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Renewable Agriculture and Food Systems

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Renewable Agriculture and Food Systems provides an international forum for original research and review articles on the biological, physical, social science, and policy aspects of alternative agriculture and food systems, focusing on the effective use of renewable resources and biodiversity in agro-ecosystems. The journal particularly welcomes multidisciplinary, holistic, systems research that addresses the multiple challenge of economically meeting basic human needs for food, fiber, and energy while maintaining essential natural and environmental resources.

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Email: rafs@cabi.org

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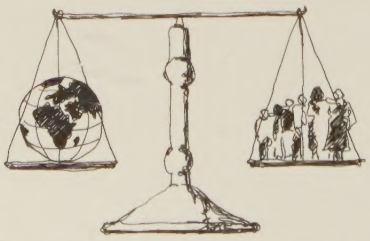

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CAB International
Wallingford
Oxon OX10 8DE
UK
Tel: +44(0)1491 832111
Fax: +44(0)1491 829292
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For Customers in North America:
CABI Publishing North America
875 Massachusetts Avenue
7th Floor
Cambridge
MA 02139
USA
Tel: +1 617 395 4056
Fax: +1 617 354 6875
E-mail: cabi-nao@cabi.org

Managing Editor: Sarah Peck
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Renewable Agriculture and Food Systems
c/o Emma Durman
CABI Publishing
Nosworthy Way
Wallingford
Oxon OX10 8DE
UK
Email: rafs@cabi.org

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Improved manure management and utilization: A systems approach

Laura McCann[1,*], Charles Abdalla[2], Mark Jenner[3], and Ray Massey[1]

[1]Department of Agricultural Economics, 214B Mumford Hall, University of Missouri, Columbia, MO 65211, USA.
[2]Department of Agricultural Economics and Rural Sociology, 201B Armsby Building, Pennsylvania State University, University Park, PA 16802, USA.
[3]Renewable Resource Economist, 714 Poplar Street, Greenville, IL 62246, USA.
*Corresponding author: McCannL@missouri.edu

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Abstract

The manure issue is complex and inherently interdisciplinary but, more fundamentally, it requires systems thinking. Current policies, technologies, infrastructure, incentives and modes of thinking about the problem fail to consider the system-wide implications, and thus fail to foster the creation of new and innovative solutions. At the farm level, complexity, uncertainty and lack of compatibility with the current farming system need to be addressed in order to promote better manure management. Production facilities, feed management and waste treatment systems (including centralized treatment plants) need to be designed to allow for beneficial use of manure components. At the industry level, changes in the poultry, swine and beef industries have resulted in concentration, both in terms of decision-making and geography. This currently limits the ability of these farmers to take a systems approach to livestock production. Environmental policies thus need to take account and advantage of this new reality. At the economy-wide level, factors affecting the demand and supply for alternative manure products need to be considered. A number of innovative uses are being developed in the private sector, but there are constraints as far as technology, institutions and infrastructure are concerned. A systems perspective will allow the design of policies and technologies that reduce environmental problems associated with manure, while promoting efficient utilization of the resource.

Key words: livestock industry, manure management, nutrients, systems approach

Introduction

Manure has the potential to be a valuable source of plant nutrients and improved soil tilth, as well as a source of energy and fiber. However, under certain circumstances, manure can also be a source of environmental problems across multiple media. Water-quality problems associated with manure include microbial pathogens, excess nutrients in surface and groundwater, and accumulation of heavy metals. Air quality problems associated with manure are receiving increased attention, and include ammonia, greenhouse gases, particulates and odor, which have effects on multiple geographic scales. Some rural residents are opposed to large livestock operations, due to the air and water quality concerns, as well as the social and economic changes associated with the changing structure of the livestock industry, which has resulted in increasing specialization and geographic concentration. As a result of these and other concerns, the US Environmental Protection Agency (EPA) has issued new federal water-quality regulations for concentrated animal feeding operations (CAFOs) and is considering a new air regulations.

In this article we stress that a systems perspective is key to solving problems caused by manure and making use of the resources contained in manure. The need for a systems approach has been mentioned by Grusenmeyer and Cramer[1] in the context of dairy production and by Hoag and Roka[2] in the context of hog production. Systems thinking recognizes that, particularly for complex problems, it is necessary to understand how components of the system interact with each other, rather than breaking systems down into their components and studying them in isolation[3]. When a broader system-wide view is taken, innovations can be identified which lower costs and improve overall efficiency and system performance. Most current policies, technologies, infrastructure, incentives and modes of thinking about the problem fail to consider system-wide implications and also fail adequately to

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consider all possible solutions. Systems solutions to manure management problems involve crossing a boundary of some type. One example is the boundary between disciplines. Animal agriculture is inherently interdisciplinary and the need to incorporate environmental and health impacts means that not only do a wider variety of disciplines need to be involved, but that systems thinking is required.

This paper discusses the barriers and opportunities to improving manure management performance by implementing system-wide solutions. The farm is considered the smallest system and is discussed first. Land application of manure as a fertilizer will remain an important use of manure for some time[4]. However, the farm-level decisions are increasingly impacted by industry structure as well as the wider economy. Therefore, the system boundary is subsequently enlarged to include first the industry and, secondly, utilization alternatives that go beyond land application of manure and even agriculture. The final section of the paper discusses policy issues and research implications.

The Farm

While widespread concern and regulations such as the US Clean Water Act are relatively recent, manure management problems are not. An Iowa State University Research Bulletin from 1926[5], before the commonplace use of commercial fertilizers, laments the loss of the fertilizer value of manure, although not yet recognizing the environmental impacts of the wasted nutrients. Despite the extensive research, extension and technical assistance efforts aimed at manure management, adoption of new strategies for land application of manure by farmers has been slow.

Within firms, systems solutions involve combining together multiple internal enterprises that are currently considered separately by the manager. For example, livestock producers would consider the impact of feeds on nutrient content of manure to meet crop fertilizer needs. The decision to consider both enterprises together is not costless. Modified rations may be more costly, the manure and the soils may need to be tested for nutrient content, and additional efforts will be needed to haul and spread manure on appropriate crops located beyond where it was formerly spread. Systems solutions can also involve crossing individual farm boundaries. Manure from one farm can be given, sold or bought by a neighboring farm to be used as a fertilizer, or as an input into production (e.g., mushroom production in the case of broiler litter).

While lack of profitability is important, other factors slow adoption rates. A broader, utility (i.e., well-being) maximization framework, rather than a profit maximization framework, may be appropriate for examining manure issues at the farm level, for several reasons. Utility is a function of the goods and services, both market and non-market, that an individual is able to consume or experience, and is affected by prices as well as his or her income and time constraints. This framework also allows for the disutility of uncertainty and for the full range of factors that affect well-being. Profit maximizing frameworks are not well adapted to issues where risk aversion is important and, as discussed below, uncertainty is a very important aspect of the manure problem. Sociology provides other factors affecting farmer adoption of innovations which could be addressed in a utility framework. Rogers[6] discusses status and discomfort as factors affecting adoption, and it would seem that these would be relevant for the manure problem. Nowak et al.[7] indicate that lower-status employees are usually assigned to manure management activities on the farm. Manure has an unpleasant odor, and also causes a number of health problems in farm workers[8]. In addition, farmer preferences for environmental and social goals are not expressed in a profit maximization framework. Analyzing farmer behavior using a broader framework would enable researchers and policy-makers to predict adoption of strategies and technologies, provide additional levers to affect farmer behavior, and facilitate systems thinking.

One of the reasons that systems thinking is both important and difficult is the complexity inherent in manure issues. In general, complexity increases uncertainty and thus decreases adoption of innovations[6], as well as increasing transaction costs[9]. Manure is a complex environmental problem affecting multiple media, with interactions between the various media. For example, efforts to reduce phosphorus (P) in surface runoff may lead to increased leaching of nitrogen (N) to groundwater, decreased leaching of N to groundwater may increase ammonia emissions to the atmosphere and increased moisture may decrease dust but increase odor. In addition, there are multiple biological and physical processes involved. The nutrient content of manure is a function of growing conditions and plant genetics[10]. Animal use of feed nutrients is affected by level of production, species and genetics[11]. Manure removal, storage and application systems involve biological processes that affect the nutrient content and form of the manure. Once applied to the land, complex soil and plant processes, as well as hydrology and climate, affect the environmental impact of the manure. All these factors increase uncertainty regarding environmental impacts and the fertilizer value of manure.

Systems solutions must reduce or accommodate this uncertainty regarding nutrient content and availability in order to improve the management and utilization of land applied manure. Trialing, or testing out a new innovation on a small scale, is often used by farmers to reduce uncertainty, but this is not an attractive option given time lags and the large investments that are often required for manure management systems. Given the large number of factors affecting the composition of applied manure, quick, convenient and reliable manure nutrient tests would eliminate some of the uncertainty involved with the use of manure as fertilizer[12].

A number of other factors limit the substitution of manure for commercial fertilizers, including nutrient ratios, compatibility with existing systems and transportation costs. A fundamental system-wide problem with manure as a fertilizer is that plant nutrient needs don't correspond with the nutrient ratios in manure, and this is particularly problematic with some species and some types of treatment systems[12]. Another problem is that animal nutrient requirements and the available nutrients in feedstuffs are also not well-aligned[10]. Farmers have to use supplemental phosphorus in swine and poultry diets since P in typical diets has low digestibility for non-ruminants. The amino acid profile in plants is not the same as animal requirements, so to meet requirements of some essential amino acids, farmers overfeed protein. Farmers can reduce excreted P and N (and thus pollution) by improvements in nutrition, such as adding phytase to diets for non-ruminants and providing a better balance of amino acids. However, even dietary changes are impacted by system constraints, such as the number of feed storage bins on a farm.

Understanding the farming system will facilitate the development of strategies and technologies to improve the substitutability of manure for commercial fertilizer, since compatibility with an existing system affects adoption[6]. For example, more emphasis needs to be placed on timing of operations over the year, not just the total hours involved, since the opportunity cost (i.e., the value of time or equipment in an alternative use) may be high at certain times of the year. Applying manure just before planting can reduce nutrient losses, but this could delay planting compared to applying commercial fertilizer. Overcoming issues of convenience and odor would make manure more competitive with commercial fertilizers. Compatibility also relates to equipment that may be needed for manure application.

The market value of manure is also affected by transportation costs, which are determined, in part, by treatment system design. For example, the high water content of manure effluent from liquid handling systems greatly increases transportation costs. Dry broiler litter has lower transportation cost per unit of nutrient and has been shipped greater distances[13] than wetter swine or dairy manures, which have generally lower or even negative economic value.

Intensive rotational grazing is an example of a sustainable agricultural practice that takes a systems approach. In intensive rotational grazing systems, the land resource serves the multiple-uses of food production, food storage, animal housing and waste disposal, thus efficiently using and recycling available resources. Among the many efficiencies gained in intensive rotationally grazed systems, 60–99% of minerals and nutrients are recoverable[14]. Since all these functions occur on the same facility, issues of transaction costs and market infrastructure are minimized. When intensively managed, environmental and economic goals are both enhanced. Given the changing structure of livestock industries, and thus the locus of decision-making, Hinrichs and Welsh[15] indicate that it may be possible to get cow–calf operations and dairy operations to adopt this technique, but that it is less feasible for the poultry and swine industries.

Fundamentally, production facilities and feed management need to be designed to reduce problems and increase utilization opportunities, rather than just focusing on what to do with manure after it comes out of the barn[1,16]. Management specialist Steven Covey[17] says we should begin with the end, in this case manure utilization, in mind. As an example, Total Quality Management has been suggested by Grusenmeyer and Cramer[1] as an appropriate strategy. Alternatively, ISO 14000 is a series of international standards which provide a framework for the development of an environmental management system[18] and which could be applied to animal agriculture. Porter and van der Linde[19] show many cases where environmental regulations have stimulated innovations that actually increase profitability because the firm is forced to overcome organizational inertia and carefully examine their whole production system. In addition, they indicate that regulations often address areas where there are resource inefficiencies and thus potential for technological and process improvements.

The Industry

Farm structure is evolving from many diversified crop–livestock farms to fewer, larger farms that specialize in either crop or livestock production. In addition, livestock producers are becoming more geographically concentrated, located in clusters near processing and infrastructure services[20]. These changes can create an imbalance between nutrients produced by livestock operations and crop needs at the farm and regional levels, which can have negative impacts on the environment[4]. Integrators, firms that contract with farmers to raise livestock while providing the feed and animals, are common. While the industrialization process has resulted in efficiencies due to economies of scale and increased use of technology, it has also produced a number of unintended consequences, including environmental consequences. Contract production means that the responsibility for decisions regarding production of livestock, and thus manure nutrient concentration, is separated from the producer-level decision-making regarding waste management. Traditional diversified farms took more of a systems approach within a local context and cycled nutrients among crop and animal enterprises, but that has been lost with industrialization so new systems and incentives need to be designed.

However, systems solutions may be possible within the food system. In essence, this represents the integration of two or more vertically aligned stages in the marketing system through greater coordination. It can be accomplished through expanded ownership or new market exchange mechanisms (such as contracting). On the input

side, the reformulation of feed mixes to reduce water or air emissions has been identified as a promising system innovation. A barrier to adoption may be that the changed feed mix or additive may be at higher costs to the integrator, while the benefit of use accrues in farm-level manure management or beyond the farm in downstream water uses. Some poultry integrators have incurred additional costs of change-over to use these feed additives, and/or required growers to utilize these less polluting types of feeds as part of their contract[21]. In Virginia, public funds have been used to help feed suppliers make the changes needed to convert their feed lines to provide phytase in a form that is usable by growers. Overcoming this bottleneck and conversion cost was critical to more widespread availability to poultry growers in that state (J. Pease, personal communication, 2001).

Viewing manure problems from a systems perspective allows new solutions to be envisioned. Co-permitting (requiring both producers as well as other entities with substantial operational control of CAFOs to obtain a permit) may have potential to introduce a systems approach. While entailing costs to integrators and other food system participants, co-permitting appears to hold promise as a way to reduce transaction costs and facilitate broader, more cost-effective solutions. In other words, co-permitting recognizes that the feed supplier/integrator/processor influences, or has primary control over, many outcomes in vertically coordinated food sectors. This approach has the ability to affect environmental externalities directly by bringing the environmental consequences of decisions to bear on the actors making the decisions. In addition, by working with the decision-making entities at the regional level, a co-permitting approach has the potential to attain regional scope or scale economies needed for cost-effective manure transport, treatment and disposal.

There are many significant unknowns related to co-permitting. For example, one of these unknowns relates to how the benefits and costs of change would be shared. Some fear that co-permitting would allow integrators to further take advantage of growers[22]. Gains from coordination and reduced transaction costs within the poultry meat industry must be weighed against pervasive economic power conflicts between some contract poultry growers and the companies who own the birds and feed[23]. Developing new manure product and service industries separate from the existing production contract relationships may diminish these conflicts. Integrators could play an important role by supporting new infrastructure development, such as grower and third-party manure processing and handling enterprises[24].

Beyond Land Application and Agriculture

A systems approach can suggest possible new ways to reuse and recycle manure into 'green' products by combining existing stages in the manure distribution chain or creating new stages. As discussed below, there is a significant and growing demand for 'green' and renewable products. A least-cost disposal strategy for managing manure emphasizes lowering costs rather than generating revenue. Creating a positive value for manure requires a goal of increasing revenue from all outputs. Investments in capital and labor to create 'green' products may be profitable. These new and alternative technologies will go beyond land-applied uses for manure.

Treatment/conversion technologies convert inputs into outputs and thus determine the supply of usable and surplus manure products. The evaluation of new manure conversion technologies requires understanding both the inputs and the desired outputs. Unfortunately, animal production systems, manure treatment technologies and regulations have not been designed to promote beneficial use. Facilities designed solely to maximize livestock revenue created forms of manure that are difficult to process into valuable outputs. Utilizing a systems approach would enable firms to use technology to capitalize on the geographic concentration of the livestock industry, which is a problem when only land application is considered.

Ultimately, manure is unused corn, soybeans and water. The concept of unused feed allows manure to be viewed more easily as a feedstock into a new technology, since it is the raw manure qualities and characteristics that determine usability. Manure conversion technologies that determine usability can be divided into biological and physical technologies. The biological conversion technologies include anaerobic microbes used in lagoons and methane digesters, aerobic microbes used in composting, and other higher-order organisms. Physical conversion technologies are more sophisticated and often require significant capital investment. These technologies include combustion[25,26], distillation of ethanol from manure[27], conversion of manure to biodiesel[28], heat and pressure for fiberboard and containers[29] and crude-oil equivalents[30], to name a few.

Demand for processed manure

There is a growing demand for organic/biorenewable products[31,32]. Manure products can meet this demand by selecting nontraditional manure processing technologies that transform the manure supply into useable products[33]. For example, anaerobic digesters produce methane gas, but to use the energy the methane must be converted to electricity and distributed consistently to electricity users. The economics of the technology, the demand for the products produced and the overall marketing system determine whether manure stocks will be used or wasted.

Effective use of manure stocks requires identifying the economic uses for the materials. These can be grouped into nutrients, soil amendments, fiber for industrial uses and energy sources. The traditional use for manure is as a substitute for the nitrogen and phosphorus in commercial fertilizers, but it is difficult to compete with the ease-of-use and lower costs of chemical fertilizers, as discussed

previously. There was often excess manure when the focus was only on nitrogen, and this situation will be exacerbated by the new regulatory focus on phosphorus, so new uses are increasingly important.

The technical benefits of adding organic matter to soils are well documented, but relatively little is understood about the economic benefits. Manure compost demand is growing in existing markets for landscaping, horticulture nurseries, topsoil, golf courses, Christmas trees and ornamental plants[31]. As these industries grow, the demand for organic amendments will also grow. Ralph Jurgens of New Era Farm Services in California, prepares large volumes of various composts with specific characteristics[34]. Demand is growing for environmental and reclamation uses of compost as well. The EPA has documented the value of quality composts for use in landfill covers, roadbeds, biofilters, erosion control, mine reclamation and wetlands restoration[35].

Manure can also be converted into new forms of nutrients, proteins and carbohydrates, by higher-order organisms, which are in greater demand than the forms found in raw manure. Two examples of these technologies use algae[36,37] and black soldier fly larvae to convert manure to other sources of feed nutrients[38].

The proteins and carbohydrates in manure can be used for industrial processes. Deland Myers[39], at Iowa State University, has developed different fiber boards from manure and bedding. In Connecticut a small firm is commercializing the process of making greenhouse pots out of pressed manure and bedding[40].

The manure energy market is emerging for solid, liquid and gaseous fuels. These markets are in various stages of development but significant distribution and infrastructure challenges remain. Solid manure can be burned directly in power plants or it can be gasified[41]. Furnaces are being developed for both on-farm and centralized off-farm use. Research continues on producing liquid renewable fuels, such as ethanol and biodiesel, from manure, even though it is not the feedstock of choice for either fuel. Anaerobic digestion of manure is the most common source of gaseous energy. Methane digesters continue to be installed, although their economic success has yet to be established[42]. A commercial 'experiment' by ConAgra and Changing World Technologies in Carthage, Missouri has produced a crude-oil equivalent from animal fat and protein[30], although manure could also be used as a substrate. That process has significant potential and produces a range of carbon-based oils and products.

Some firms receive fees for hauling away waste and dead animals, essentially buying inputs at a negative price. Many of the manure-utilization successes are based, in part, on taking someone else's organic residuals, processing it into multiple products, and selling it. For many of these technologies, margins are so small that commercial success will require involvement in multiple, complementary, markets (e.g., waste disposal, an organic soil amendment and energy). Economic success will be enhanced with the development of the market and distribution infrastructures for these products.

Manure market infrastructure

An important factor affecting the implementation of multi-farm systems solutions is the existence of market infrastructure, including intermediaries, such as manure brokers and haulers, that facilitate transactions. Though not well documented, some manure market infrastructures already exist[43]. Manures have been used to grow mushrooms for decades, and across the broiler-growing areas, broiler-house clean-out businesses remove the chicken litter and apply it to neighboring pastures. Some states, such as Pennsylvania, have attempted to enhance this infrastructure through the certification of manure brokers and haulers[44]. Missouri has a new web-based Litter Market Exchange to facilitate communication between buyers, sellers, haulers and spreaders.

The growth of US soybeans shows how, over time, infrastructure development can facilitate exchange and influence economic feasibility. It has taken more than 60 years of distribution-channel development, genetic improvements, energy savings, new processing technologies and new soy uses, to create global markets for oil and protein from soybeans. Building a new commodity marketing/distribution infrastructure for manure products will be costly and time consuming, but appropriate incentives may facilitate this process.

Policy Implications

Desirable policies are cost effective, limit unintended consequences and consider the entire system being regulated. There are four major sources of unintended consequences of social action[45]. Two are particularly relevant to manure issues: (1) uncertainty or insufficient knowledge because of the complex nature of the phenomenon; (2) error due to a lack of thoroughness or a determined refusal to consider all aspects of the problem. The multimedia nature of the manure problem means that focusing on just one component or one medium may exacerbate other problems. For example, regulations based on nitrogen have had the perverse result of providing incentives for poor manure quality as far as meeting crop nutrient needs is concerned, since reducing the nitrogen content by volatilizing it means that manure has to be applied to fewer acres. Those regulations have also promoted the surface application of manure and phosphorus build-up in the soil. An example of the second source of unintended consequences is the tendency for scientists to overlook the human dimensions of the problem.

Missed opportunities?

The EPA published new federal Clean Water Act regulations for CAFOs in February 2003[46]. The first

Table 1. A systems evaluation of the Environment Protection Agency (EPA) concentrated animal feeding operations (CAFO) rule revision.

Proposed CAFO rule element	Use of systems approach	Included in final EPA CAFO rule
Inclusion of dry poultry operations and immature stand-alone enterprises	Yes	Yes
Production and land application require permits	Yes	Yes
Phosphorus in addition to nitrogen management	Yes	Yes
Co-permitting of feed suppliers/integrators	Yes	No
CAFO definition based on animal-specific thresholds (i.e., no longer combining animal units)	No	Yes
Land application area requirements that address manure exported to other farms	Yes	No

significant changes in the rules since 1977, these regulations were a result of a court order in response to a lawsuit by the Natural Resources Defense Council. They claimed that the EPA was not implementing the Act according to schedule, resulting in inadequate protection of the water quality in the nation's rivers, lakes and coastal waters. The EPA also indicated that an important reason the rules needed to be changed was to reflect the fact that the structure of poultry and livestock industries had changed significantly since the 1970s[47,48].

Modification of the EPA CAFO rules involved two steps. In December 2000, a draft proposal offering a menu of options for revising the rules was released. After reviewing public comments on the draft and conducting required analyses, EPA released the final rules in December 2002. One can evaluate elements of the CAFO rules in terms of systems thinking, as shown in Table 1. Of the five proposed elements that incorporated a systems perspective, three—dry poultry and immature animals, land application in addition to production areas, and the inclusion of phosphorus—made it into the final EPA rules. The two that did not make it into the final rules were co-permitting and extending land application requirements to farms where manure was exported. These two elements have the following in common: each involved crossing firm boundaries and would have involved clarifying or changing property rights and costs (either rights or responsibilities) related to nutrients in feed or manure. In addition, the final rule includes an element that contradicts systems thinking; a simplified CAFO definition based on species-specific thresholds, rather than combining animal units across species. For mixed species operations, separating manure by animal species means that the total manure, and the environmental threat potential, could be equivalent to a single-species operation, yet the operation would not be required to have a permit.

In addition, the new regulations did not foster efficiency improvements, feed formulation and genetics as means to reduce environmental impacts. The new regulations do little to provide incentives for alternative uses of manure, and often even hinder potential market solutions. For example, the potential for composted manure is not addressed, even though the EPA itself recognizes the environmental benefits. Treated manure is codified as a waste and liability, and regulations do not connect the permitted facilities to new uses for manure.

The political economy surrounding livestock production and marketing may present a barrier to the successful implementation of systems solutions. If a change is costly to certain groups, and they have significant economic or political power, they will likely block the change. For example, poultry and cattle producers actively opposed proposals at the national level and in Maryland to incorporate co-permitting of integrators that contract with farmers in order to meet the goals of water quality and nutrient management laws[49,50].

More generally, systems solutions are also possible within natural resource boundaries, including watersheds and airsheds, but face a number of obstacles. Natural boundaries rarely coincide with economic, social or political boundaries. Costs and benefits are experienced by different groups. For example, farms located in tributaries of a watershed may be important generators of manure nutrients and contribute to excess nutrient loads downstream, leading to pollution problems and loss of fishing, recreation or others uses and benefits. Greater efforts toward improved manure management would likely increase the costs for upland farms, and since they are unable to capture the environmental benefits of these efforts, given current institutional arrangements, they have little incentive to change practices.

Research is needed on policies and institutions that allow those benefitting from water quality improvements to compensate those that experience added costs. A possible system-wide solution would involve a negotiated or 'market-like exchange', whereby the winners compensate the losers. The EPA is examining the potential for water-quality trading, and recently released a water-quality trading policy[51]. While some success with trading in the air pollution context has occurred, there has been limited success in water-quality issues. Among the barriers encountered have been high transaction costs, lack of, or unclear, property rights[52] and high information costs associated with linking water-quality changes to land uses[53].

There are other positive developments. The USDA-NRCS Environmental Quality Incentives Program (EQIP) provides incentives for systems approaches to improve environmental quality impacts from agriculture. The program now focuses more heavily on animal agriculture

than in the past. Cost-sharing is available for intensive rotational grazing systems. In addition, comprehensive nutrient management plans are required for most animal feeding operations in order to receive EQIP funds. Innovative public policies, such as the renewable energy portfolio and the green product procurement programs, are stimulating demand for organic and biorenewable products. These programs, as well as guaranteed loan and grant programs, act as a sort of venture capital to jump-start new industries. Other private-sector efforts, such as the US Composting Council's Seal of Testing Assurance, create a label that assures a minimum quality, similar to regulated feed and fertilizer labels[54].

More policies that reflect systems thinking are needed. At the farm level, EQIP represents a step in the right direction. Policies that increase the substitutability of manure for commercial fertilizer by addressing the existing farm-level constraints need to be developed in light of phosphorus-based regulations. Policies should also recognize the constraints and opportunities presented by structural changes in agriculture. There must also be incentives to create manure solutions, by focusing on both demand and supply issues, rather than just focusing on what to do with manure as an afterthought. In some cases, there is a lack of research-based information on which to base decisions.

Research Implications

Increased knowledge regarding the physical processes related to manure cannot, by itself, overcome the problem of unintended consequences. A commitment to systems thinking and to a process of thorough analysis of manure issues and potential consequences and opportunities is required. At the farm level, agricultural research, extension and technical assistance programs should take into account the full range of constraints faced by farmers if innovations are to be adopted. Technologies that increase the substitutability of manure for commercial fertilizers, by reducing uncertainty and increasing quality and convenience, need to be developed.

Technologies and production systems that improve the suitability of manure for industrial and energy uses should be developed. Some research is already occurring in both the public and private sectors, but new policies could facilitate these efforts. Research on the links between agricultural and environmental policies and the incentives for development of new industries will require a systems perspective. The effect of industry structure, infrastructure and marketing channels on the development of value-added manure industries must be examined. Systems analysis of the existing institutions and property rights that determine incentives at the farm, industry and economy-wide levels is needed.

Concern regarding the effects of animal agriculture on air quality from esthetic, health and global warming perspectives is increasing. Scientific research on air-quality concerns, as well as interactions between air quality and water quality, is needed. Research is also needed to design environmental policies that are appropriate for situations where there are multiple media, multiple pollutants and high levels of uncertainty. Systems, rather than reductionist, thinking is obviously required.

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Priority setting in agricultural land-use types for sustainable development

Nevin Akpinar[1], Ilkden Talay[1,*], and Sema Gun[2]

Ankara University, Faculty of Agriculture, [1]Department of Landscape Architecture and [2]Department of Agricultural Economics, 06110 Diskapı, Ankara, Turkey.
*Corresponding author: talay@agri.ankara.edu.tr

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Abstract

Even in developing countries that are faced with ecological and socio-economic problems, agricultural areas are constrained by land-use laws to be developed in particular ways. This being the case, the major issues in these areas are a better quality of life and sustainable use of the limited resources. This necessitates planning for sustainable development and evaluating various qualitative and quantitative data in a single framework. Multicriteria or multipurpose decision analysis methods are appropriate for this purpose. Using these methods, physical, economical and social data, as well as planning goals, can be combined and evaluated in the context of sustainable development. These multicriteria methods have been documented widely in a variety of problem areas, but two multicriteria methods, namely AHP (analytic hierarchy process) and ELECTRE II (elimination and choice translating reality), have not been used extensively in agricultural land-use decisions in developing countries. However, in situations where decision-making criteria are non-commensurable, non-comparable or non-countable, and when it is necessary to evaluate the criteria together, as in agricultural land-use decisions, AHP and ELECTRE II methods are warranted. This study reviews these methods briefly and suggests their potential application in the agricultural land-use decision process in a developing country. For this purpose, these methods were sampled in Ziyaret Stream Basin in Adiyaman, which is part of the Güneydoğu Anadolu Projesi (GAP) (South-eastern Anatolian Project) in the Republic of Turkey. The area could be characterized by its rural and agricultural features, although it is under the pressure of Adiyaman urban development. This study shows that both AHP and ELECTRE II methods can be applied successfully for the determination of agricultural land-use priorities, which are an essential part of the quality of life and of sustainable land-use studies.

Key words: agricultural land use, AHP (analytic hierarchy process), ELECTRE II (elimination and choice translating reality), GAP (South-eastern Anatolian Project), multicriteria analysis

Introduction

Over the past decade, sustainable development has become a main concern for planners and policy makers in both developed and developing countries. Rational use and conservation of renewable and non-renewable resources and the balance of ecology and economy are essential to enhance the quality of life and to achieve a sustainable future at global level.

Land-use planning and management in agriculture are effective tools to achieve sustainable development. Determination of the suitability of land-use types for a certain area, that is, setting the priority of agricultural land-use types, is an important part of land-use planning. Various factors are involved in setting the priority for agricultural land-use types. Some of these factors are qualitative, while others are quantitative. Multicriteria analysis and decision-making methods are suitable techniques for combining and evaluating the qualitative and quantitative data.

Multicriteria analysis is a methodology for ranking alternatives based on evaluation criteria, weighted by the user. It provides a rational methodology for decision making in the face of uncertainty[1]. For this purpose, many multicriteria analysis methods can be used, depending on the nature of the information and scope of the study. Most of these methods are based on the pairwise comparison principle. AHP (analytic hierarchy process), PROMETHEE (preference ranking organization method for enrichment evaluations), ELECTRE (elimination and choice translating reality)[2], SAW (simple additive weighting), MEW (multiplicative exponential weighting), TOPSIS[3] and SMART are the most common methods[4]. Among these multicriteria analysis and

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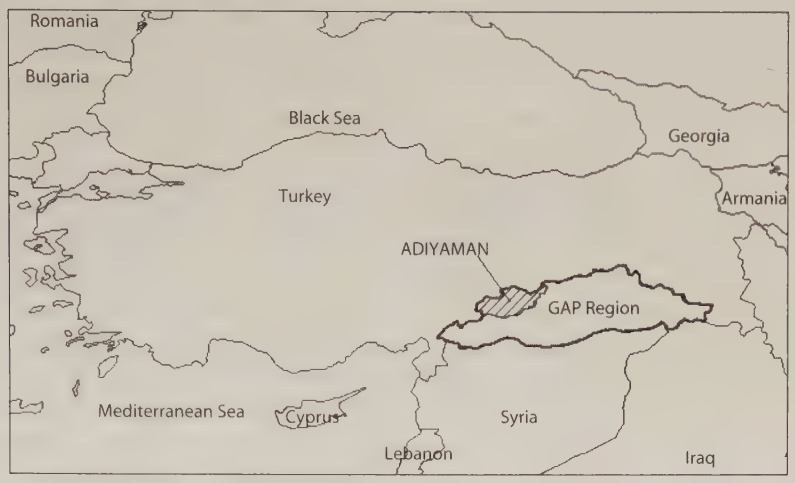

Figure 1. Location of the sample area.

decision-making methods, ELECTRE has been applied to various case studies in the planning process[5–9].

While some of these studies focused on planning or management of a specific area, such as a river basin, the others focused on different sectors such as energy, economy, etc.

Most of these case studies were carried out to investigate the performance of some multicriteria decision-making methods[1–3,10–12]. Some multicriteria decision methods were applied and compared in these studies. The basic differences between these methods can be summarized as: (1) different algorithms in choosing the best solution; (2) differences in using criteria weights in calculations; and (3) introducing additional parameters that affect the choice.

Colson[13] has reviewed the extensive literature regarding multiple criteria analysis. The ranking approach to this analysis and its principal method, ELECTRE, has received the most attention recently. More often, real-world applications of this method involve small teams of decision makers. Another branch of decision aid is concerned with facilitation of small group meetings, involved in ranking projects or candidates, and several pieces of software have been designed for this purpose. Few of them are focused at the junction of both approaches, allowing them to deal with ranking in the framework of small-team decision making.

In the past few decades the AHP has also been applied to numerous practical problems in decisions on crop pattern, land-use planning and environmental impact assessment[14–19].

Although many multicritera methods have been used widely in a variety of areas, as mentioned above, multicriteria methods have not been used extensively in agricultural land-use decisions in developing countries, in spite of the growing need for introducing quantitative techniques in all planning fields.

The main aim of this study was to sample priority settings in agricultural-land use types using AHP and ELECTRE II, which are two basic methods applicable to a developing country. These two methods have been used in two different phases of the study. AHP was used to assign weights to criteria, which were then used in the context of ELECTRE II.

AHP was chosen for two basic reasons:

(1) to consider all the attributes affecting the planning at the same time; and
(2) to evaluate all the criteria affecting the planning in an analytical set[15].

ELECTRE II was used to carry out multicriteria analysis of alternative land-use types. This method was chosen to mix and evaluate qualitative and quantitative data in the same framework.

In order to sample the priority setting of agricultural land-use types, the Ziyaret Stream Basin in Adiyaman Province, which is part of the regional development project called the South-eastern Anatolia Project (GAP: Turkish acronym), was chosen as the sample area (Fig. 1). GAP, which covers one of the less-developed regions of Turkey, is a large-scale and multisectoral regional development project, the purpose of which is sustainable development; it is the largest and most comprehensive enterprise ever carried out in Turkey[20]. The GAP area covers 75,308 km^2. Agriculture is by far the dominant production sector, accounting for nearly 40% of the gross regional product (GRP) in the GAP area. Agriculture contributes over 9% of the agricultural value-added product of Turkey. Nearly 70% of the economically active population is engaged in agriculture, but traditional production methods still predominate[21]. Traditional agricultural land-use patterns and misuse of land and other natural resources are also observed in the region. The population is expected to reach 10 million in the GAP region by 2005.

The GAP area is rich in water and soil resources. The development of the region was originally planned around its water resources. As part of this goal, projects were designed to make use of the Euphrates and Tigris rivers[21]. Project planning and implementation are based on a master plan prepared by the Republic of Turkey Prime Ministry GAP Regional Development Administration, as an

assessment of the region's potential and the objectives, goals and strategies of development. In addition, basic sustainability goals have been adapted to the GAP master plan by the GAP Regional Development Administration. One of the basic components of the GAP master plan strategies is to improve land use through optimal agricultural patterns and agricultural practices[22]. The basic development scenario of the GAP master plan is to transform the region into an export base for its agricultural products. When the project is completed, the ratio of irrigated land to the total GAP area will increase from 2.9% to 22.8%, while that for rain-fed agriculture will decrease from 34.3% to 10.7%. As a direct result of the introduction of irrigation, agricultural production and crop variety will increase substantially[22].

In light of the strategies and development scenario of the GAP master plan, mentioned above, it is clear that significant land-use change will occur in the near future in the sample area. Additionally, the sample area lies in the western part of Adiyaman settlement, in the urban periphery, and is under the pressure of urban development. The rapid development process imposed by GAP has not considered neglect or damage to the environment. Thus, proper evaluation of priorities regarding agricultural land-use types has great importance in the area.

This study was carried out using multicriteria methods, in order to provide ranking for ecologically, economically and socially acceptable agricultural land-use types in the sample area. In the study, eight alternative agricultural land-use types were ranked according to their suitability and importance, using the ELECTRE II method. The weights of 15 criteria were determined using the AHP (analytic hierarchy process). This paper is a modest attempt in ranking agricultural land-use types using multicriteria methods.

Main Characteristics of the Sample Area

The sample area covers 66.5 km^2. The Ziyaret Stream, which is in the sample area, feeds the Atatürk Dam. There are three villages named Ziyaretpayam, Yenigüven and Çemberlitaş in the sample area. The altitude of the area is between 520 and 870 m. The area is characterized by slopes varying from 0 to 3% (41% of the total area). The south-facing areas are 54% of the total. The geomorphologic structure increases the visual landscape qualities, which add to scenic value and tourism potential of the area. Reddish and brown soil groups cover a great part of the area. While land capability class I covers only 11% of the total area, over 55% of the area is covered by classes II, III and IV. Most of class I is in the east of the urban development zone and is affected by the development[23–26]. Wind erosion is limited, but soil erosion by running water is a serious problem in the sample area. Approximately 80% of the total area is exposed to moderate and high-level erosion[26]. Traditional farming practices and lack of forests are the main factors in the erosion.

Dry farming is the primary type of land use, covering 52.1% of the area, while 33.4% of the area is pasture land. Vineyards cover 9.2% of the area, 3.3% of the area is bare land, and irrigated land-farming covers only 1.6% of the area (Fig. 2).

Climatic conditions in the area are dependent upon the continental climate. Winters are severe, with an abundance of snowfall. The average annual temperature of Adiyaman is 17°C, and average annual rainfall is 771.2 mm[27].

Nearly 80% of the employed population is engaged in agriculture[28], but it only generates 44% of total economic activity. The proportion of the unemployed population in the region is 30.95%, which is a much higher proportion when compared with the wider GAP region and Turkey. The head count of livestock is large, but productivity is low. Traditional production methods still predominate, but agricultural modernization has only just begun[22].

Sacred visiting places and tombs, such as Mahmut Ensari and Abuzer Gaffari and the archeologically important Pirin caves, provide the potential for tourism in the region.

Procedure

The phases of this study involved data collection, selection of an evaluation method, selection of the alternative agricultural land-use types, determination of criteria and assignment of their weights using AHP, and priority setting using the ELECTRE II method.

Data collection

Data were collected from digitized and traditional thematic maps, databases from the State Institute of Statistics (SIS) and field surveys. Spatially variable sets of vector data were collected, evaluated and integrated using ArcView 3.2 GIS (Geographical Information System) software.

Selection of evaluation methods

In ranking or setting the priority of land-use types, techniques are essential which combine and evaluate ecological, economical and social data and goals, using known multicriteria or multipurpose decision-making methods[29].

In situations where decision-making criteria are non-commensurable, non-comparable or non-countable, and when it is necessary to evaluate the criteria together, the ELECTRE method is warranted.

Among the set of multicriteria analysis methods available, ELECTRE II was chosen as the outranking method for this study. When compared to other multicriteria methods there were no remarkable differences in the solutions. ELECTRE II was chosen as it is well suited to the land-use planning process[30], the criteria of which are often extremely diverse in that they cover economic, ecological or sociologic characteristics, and the method incorporates both qualitative and quantitative types[31].

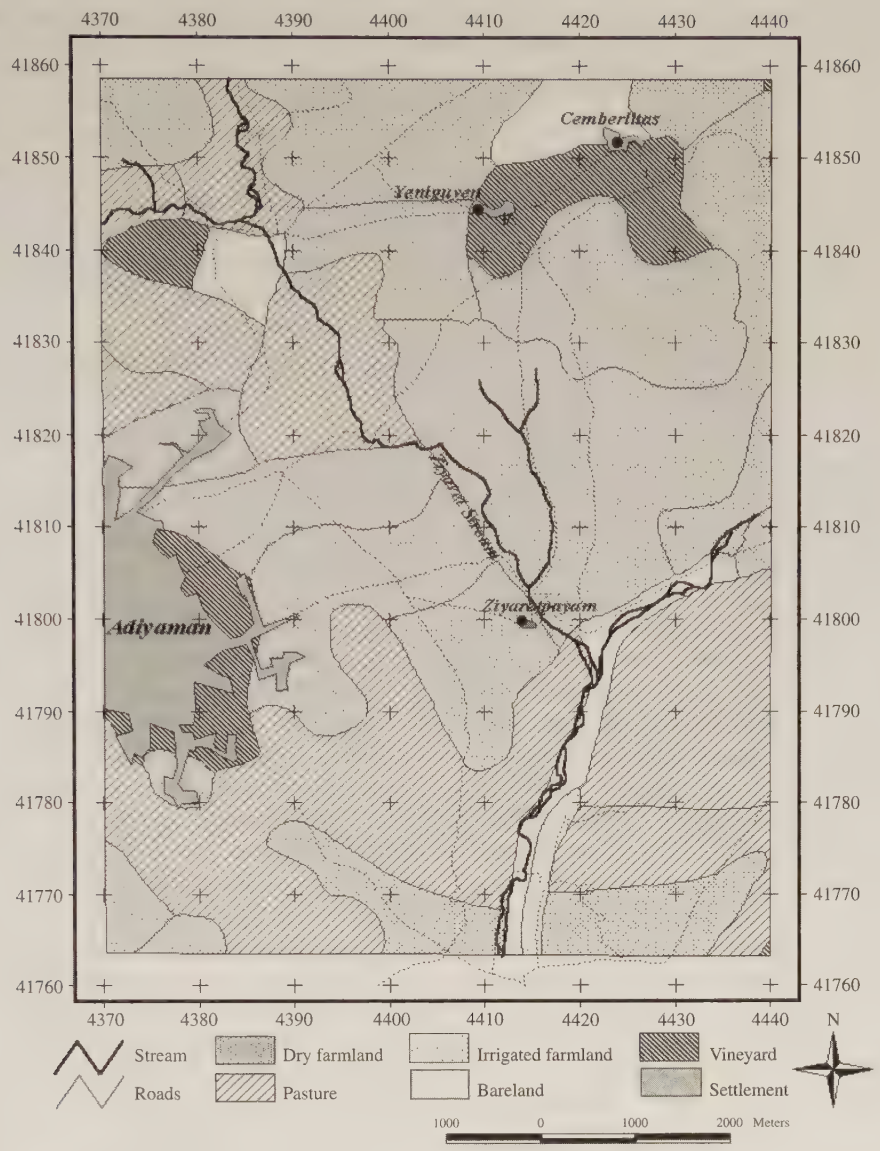

Figure 2. Existing land use of the sample area.

ELECTRE II method

The ELECTRE II method is a pairwise comparison between alternatives. It measures concordance, $c(i, j)$, and discordance, $d(i, j)$, for each pair of alternatives. It also defines two relationships using the strong and weak relationship graphs. Based on this information, a ranking for each alternative is determined. For ELECTRE II, three parameters c_1, c_2 and c_3 represent three increasing levels of concordance and two parameters, d_1 and d_2, represent increasing levels of discordance[1].

In this method, an alternative A1 strongly outranks A2 when the following three conditions are met simultaneously:

$$W^+/W^- \geq 1$$

$$C_{12} = (W^+ + W^-)/W \geq c_1$$

$D_{12} = \max[g_k(\text{A1}) - g_k(\text{A2})] \leq d_2$ for discordant criteria.

Or, alternatively, when the following conditions are met[32]:

$$W^+/W^- \geq 1$$

$$C_{12} \geq c_2$$

$$D_{12} \leq d_1$$

There is a weak outranking relationship when the following three conditions are fulfilled simultaneously[32]:

$$W^+/W^- \geq 1$$

$$C_{12} \geq c_3$$

$$D_{12} \leq d_2$$

The definitions and abbreviations in these formulas are[32]:

C_{12}: concordance index between the A1 and A2 alternatives.

W^+: in situations where $[g_k(\text{A1})] > [g_k(\text{A2})]$ the sum of criteria weights.

$W^{=}$: in situations where $[g_k(A1) = [g_k(A2)]$ the sum of criteria weights.
W^{-}: in situations where $[g_k(A1) < [g_k(A2)]$ the sum of criteria weights.
W: $(W^{+} + W^{=} + W^{-})$.

D_{12} (discordance index), in $[g_k(A1)] < [g_k(A2)]$ situations between A1 and A2 alternatives.

In these formulas, c values are concordance thresholds and verify that $1 > c_1/c_2/c_3 > 0$ and d values are discordance thresholds. It has to be verified that $d_2 > d_1 > 0$.

AHP (analytic hierarchy process)

According to Quaddus and Siddique[33], consideration of multiple criteria is one of the important issues of sustainable development. They proposed the use of a multiple criteria tool called AHP within the group decision support process for solving strategic decision problems. Modeling with a hierarchy or tree is not a new concept. However, the AHP has some unique modeling features that deserve attention. AHP expresses one's mental model in an analytical framework. It has three basic principles, which are: decomposition, weighting (comparative judgments) and synthesis. The decomposition principle calls for structuring the hierarchy to capture the basic elements of the problem. Comparative judgments call for setting up a matrix to carry out pairwise comparisons of the relative importance of the elements. Finally, priorities are synthesized from the second level down by multiplying local priorities by the priority of their corresponding criterion in the level above and adding them for each element in a level according to the criterion it affects. Via weighting of the elements and synthesizing priorities at different levels, AHP provides the best solution as perceived by the decision makers[33].

The AHP is a qualitative technique, which relies on the judgment and experience of decision makers to prioritize information for making better decisions. Another advantage of using AHP is that it results in better communication, leading to a clearer understanding and consensus among members of decision-making groups[19]. In the light of these findings, AHP was also chosen as the multicriteria analysis method to assign weights to criteria for this study.

In the AHP method for an $n \times n$ matrix, in calculating the CI (consistency index) and CR (consistency ratio), the following formulas have been employed[34–36]:

$$U_{max} = \text{the largest eigen value}$$

$$CI = (U_{max} - n)/(n - 1)$$

$$CR = CI/RI.$$

In the calculations of these values, $CR < 0.1$ are desired[37].

A consistency ratio above 0.1 requires revisions of the judgments in the matrix[17,34]. RI values are random consistency values, and every RI value that corresponds to an n value is taken to make the calculations, as recommended by Saaty[34].

Selection of alternative agricultural land-use types

Suitable land-use types were determined by considering the attributes and general structure of the region in the context of the goals of the study. Eight alternative agricultural land-useo types were selected for evaluation. These were: dry farming (LUT1), pistachio plantation and vineyard (LUT2), orchards (LUT3), vegetable agriculture (LUT4), afforestation for conservation (LUT5), agroforestry (LUT6), pasture (LUT7) and agricultural recreation (LUT8).

Acronyms and brief explanations of selected agricultural land-use types for evaluation are given in Table 1.

Results

Selection of criteria and assignment of weights using AHP

In this study, 15 evaluation criteria were selected given the goals, concepts and methods of the study, as well as the data available. Two group meetings were held to select the evaluation criteria and to assign weights to these criteria.

The first meeting was organized by the Adiyaman governor and held by the planning team in March 2000 to set the evaluation criteria. The GAP Regional Development Administration, Adiyaman Municipality, General Directorate of Rural Services, Provincial Directorate of Forestry, General Directorate of State Hydraulic Works and General Directorate of Public Works and Housing were represented in the meeting by their experts. At this meeting the participants reached a consensus on the 15 evaluation criteria. Six of the criteria were quantitative, and the other nine qualitative. The evaluation criteria consisted of three main groups: (1) natural aspect; (2) cultural and socio-economic aspect; and (3) land-use goals and politics.

Natural aspect criteria were divided into three subsets: topography (C_1), soil (C_2) and water supply (f). Topography (C_1) was described by the factors: elevation (a), slope (b) and exposure (c). Soil (C_2) was described by the factors: land capability class (d) and erosion level (e).

Cultural and socio-economic criteria were divided into four subsets: existing land use (g), economic structure (h), demographic structure (i) and land ownership (j).

Land-use goals and political criteria are described by the factors: prime farmland preservation (k), diversity in agricultural pattern (l), creation of regional employment opportunities (m), income level increases (n) and recreational opportunities (o).

The first step in AHP is to establish a hierarchy of criteria. In this context, a set was established to compare all criteria and their factors with each other. This set is illustrated in Figure 3. After establishing the set, reciprocal matrices were formed to evaluate criteria and their factors in the context of AHP. An example of a pairwise comparison matrix to assess the weights of the criteria is

Table 1. Acronyms and brief explanations of selected agricultural land-use types.

Acronyms of land-use types	Land-use types	Brief explanation
Agriculture		
LUT1	Dry farming	Takes place in existing land-use pattern; mainly wheat and legumes
LUT2	Pistachio plantation and vineyard	Specific species of the region and grown at present
LUT3	Orchard	Considering irrigation opportunities
LUT4	Vegetable agriculture	Considering irrigation opportunities
Forestry		
LUT5	Afforestation for conservation	In order to prevent erosion
LUT6	Agro-forestry	To combine fast growing tree types and vegetable agriculture
Pasture		
LUT7	Pasture	To support animal husbandry in the area
Agricultural recreation		
LUT8	Agricultural recreation	To combine agriculture and recreation and to provide recreational opportunities to Adiyaman urban residents

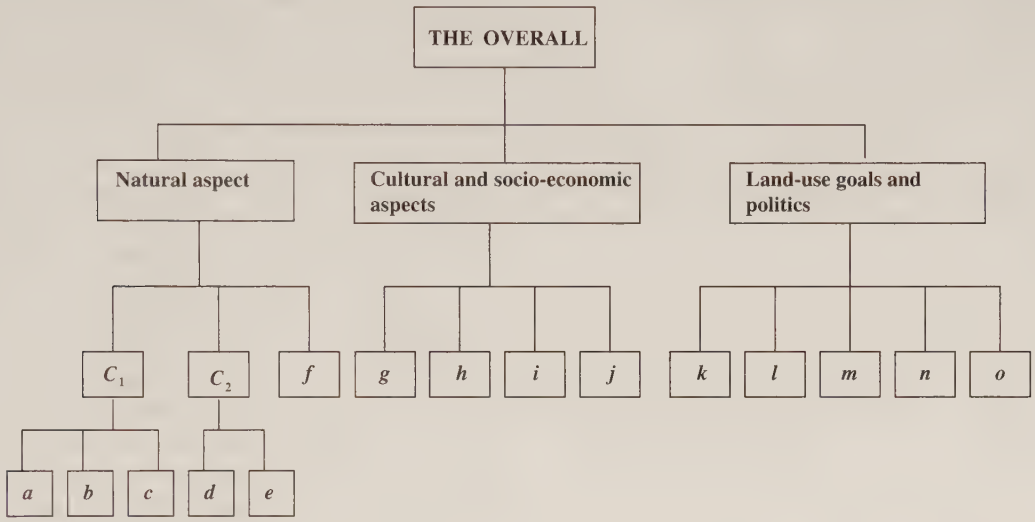

Figure 3. Hierarchy level of the criteria.

given in Table 2. Due to space restraints, not all tables could be presented here.

The Delphi method was applied by the planning team in the second group meeting on September 2000 to set judgment matrices with pairwise comparisons in the AHP. This meeting was held with a wide range of participants in order to involve all the stakeholders of the region. The representatives in the first meeting and the representatives of the other stakeholder groups were present here. The stakeholders in this meeting were grouped as: national government, local government, local people, non-governmental organizations and private sector. This meeting was held with 31 participants and lasted 2 days. On the first day of the meeting the participants were informed about the proposed project and discussed the project and the criteria. The second day of the meeting was held to assign weights to the criteria. Under the leadership of the planning team, the possible weights for the criteria were discussed, and by the end of the meeting each participant assigned weights between 1 and 9 for the criteria on separate evaluation forms.

These separate forms were then evaluated by the planning team, and arithmetic means of all the weights were taken to reach one value, so that the obtained results could be more objective and a high level of consistency could be achieved. Then, for every pairwise comparison matrix, the maximum eigenvalue, consistency index and consistency ratio were calculated. In these calculations, simple software developed in DOS by Karakaya[38] was used. When the percentage of inconsistency was less than 10%, then validity increased, and the judgments were satisfactory. Weights for every criterion were calculated by considering the calculations obtained from all the matrices and the effects of criteria on each other according to the hierarchy. All eigenvalues in the matrices, which resulted from every criterion group, were correspondingly evaluated

Table 2. Comparison of the socio-economic and cultural criteria.

	Existing land use	Economic structure	Demographic structure	Land ownership	Associated eigenvalue (weight)
Existing land use	1	1/9	1/5	1/7	0.04014
Economic structure	9	1	3	3	0.52526
Demographic structure	5	1/3	1	1/3	0.14805
Land ownership	7	1/3	3	1	0.28656

Associated eigenvalue: 4.17692; consistency ratio: 0.06553; percent of inconsistency: 10.0000; consistency index: 0.05897; random consistency: 0.90000.

with their own subgroup, and these were collected in Table 3. As a necessity of the hierarchy set, every criterion was affected by the evaluations of its previous set (Fig. 3 and Table 3).

In this calculation:

$$\text{Weight of criterion} = (W \times W1) \times W2$$

For example, for elevation:

$$[W(\text{natural aspect})] \times W1 \ (\text{topography}) \times W2 \ (\text{elevation}) = (0.54995 \times 0.44343) \times 0.1627 = 0.0396; 0.0396 \times 100 \approx 4$$

was obtained as the weight for elevation. (All values are multiplied by 100 and rounded to an integer to simplify the calculations.)

Setting the priority using ELECTRE II method

In setting the priority, all evaluating criteria (qualitative and quantitative) were divided into different subclasses. The quantitative criteria and their subclasses were:

- Elevation (*a*) (four subclasses): 520–620 m, 620–720 m, 720–820 m, >820 m.
- Slope ratio (*b*) (six subclasses): 0–3, 3–10, 10–20, 20–30, 30–50, >50%.
- Exposure (*c*) (five subclasses): flat areas (FA), facing north (FN), facing south (FS), facing east (FE), facing west (FW).
- Land capability class (*d*) (seven subclasses): class I, II, III, IV, VI, VII, VIII.
- Erosion level (*e*) (four subclasses): no erosion or low (*e*1), moderate (*e*2), high (*e*3), very high (*e*4).
- Land ownership (*j*) (two subclasses): private land (PA), public land (PUA).

After deciding on the subclasses for quantitative criteria, the areas covered by these subclasses, which are suitable for the related agricultural land-use type, were measured. The distribution of criteria subclasses considered suitable for selected agricultural land-use types is illustrated in Table 4.

The qualitative criteria were: water supply (*f*), existing land use (*g*), economic structure (*h*), demographic structure (*i*), preservation of prime farm land (*k*), diversity in agricultural pattern (*l*), creation of employment opportunities (*m*), increasing income level (*n*) and providing recreational opportunities (*o*). These qualitative criteria can assume five subjectively determined values: very high (5), high (4), medium (3), low (2), very low (1).

The real and relative values from the evaluation were then placed in the initial matrix (Table 5). For example, land capability classes I, II and III are accepted as land suitable for use in dry farming (LUT1), and the total land area falling within these three classes was found to measure 22.5 km^2. Therefore, this value was placed in the initial matrix as the LUT1 value for criterion *d*.

In assigning relative values for qualitative criteria, the Delphi method was applied and consensus values gathered by this method have been used. All real and relative values obtained from measurement of the total land area and the assigned values are shown in the initial matrix (Table 5).

The initial matrix must be normalized to evaluate all criteria together in the context of the ELECTRE II method. All values were converted to commensurate values. During the this process, the maximum value was set equal to 1, and interpolation was used to find normalized values. In our study, the maximum value for quantitative criteria was taken as 66.5 (total surface of the sample area as ha), and the maximum value for qualitative criteria was taken as 5 (5 = very high). This resulted in a new matrix called the evaluation matrix (Table 6).

Using the evaluation matrix, the concordance and discordance indices were calculated, and the concordance and discordance matrixes formed. In this process, comparisons and calculations were carried out using Microsoft EXCEL software. These matrices can be seen in Tables 7 and 8. To carry out the last evaluation, the thresholds c_1, c_2, c_3 and d_1, d_2 were determined. Considering these thresholds, all land-use types were outranked. In this study, $c_1 > c_2 > c_3$ in which $c_1 = 0.85 > c_2 = 0.75 > c_3 = 0.60$. For discordant thresholds, $d_2 > d_1$, as $d_1 = 0.5$, $d_2 = 0.7$ were accepted for the criteria in which assigned weights were between 9 and 13 (for criteria *b*, *d*, *e*, *f*, *h*, *k*). For discordant thresholds, $d_1 = 0.2$, $d_2 = 0.5$ were accepted for the criteria in which assigned weights were between 1 and 7 (for criteria *a*, *c*, *g*, *i*, *j*, *l*, *m*, *n*, *o*).

The relationships among alternative agricultural land-use types were determined considering concordance and

Table 3. Eigenvalues and weights of the criteria.

Main criteria	Subset 1	Subset 2	*W* (within main criteria)	*W1* (within subset 1)	*W2* (within subset 2)	Overall	Weight of criterion
Natural aspect			0.54995				
	Topography			0.44343			
		Elevation (*a*)			0.1627	0.0396	4
		Slope (*b*)			0.5407	0.1318	13
		Exposure (*c*)			0.2966	0.0723	7
	Soil			0.38737			
		Land capability (*d*)			0.5	0.1065	11
		Erosion level (*e*)			0.5	0.1065	11
	Water supply (*f*)			0.16920		0.0930	9
Cultural and socio-economic aspects			0.20984				
	Existing land use (*g*)			0.04014		0.0135	1
	Economic structure (*h*)			0.52526		0.0975	10
	Demographic structure (*i*)			0.14805		0.0343	3
	Land ownership (*j*)			0.28656		0.0642	6
Land-use goals and politics			0.24021				
	Preservation of prime farm land (*k*)			0.48057		0.1154	12
	Diversity of agricultural pattern (*l*)			0.06356		0.0152	2
	Creating employment opportunities (*m*)			0.19236		0.0462	5
	Increasing income level (*n*)			0.22368		0.0537	5
	Providing recreational opportunities (*o*)			0.03983		0.0095	1

discordance thresholds. After evaluating these relationships, the preference graph was drawn (Fig. 4). For example:

$$C_{LUT2-LUT1} = 0.9 > c_1$$

$$D_{LUT1-LUT1} = 0.5 < d_2$$

Accordingly, between LUT2 and LUT1, and from LUT2 to LUT1 there is a strong preference. From the analysis of the preference graph, the table of direct arrangement was prepared (Table 9). The opposite classification was also given in a table of inverse arrangement (Table 10). Direct arrangement of alternative agricultural land-use types and inverse arrangement of alternative agricultural land-use types was also given in Tables 9 and 10. Consideration of the data in both tables allows for the following conclusions:

- The first outranking was obtained by considering a direct arrangement that is determined according to the number of arrows coming to an alternative agricultural land-use type (according to an alternative's dominance). When the calculation was done considering only strong preference, the outranking was:

$$LUT2 = LUT > LUT3 = LUT5 = LUT6 > LUT1 = LUT4 = LUT7.$$

- When the calculation was done considering strong and weak preferences together; the outranking was:

$$LUT2 > LUT8 > LUT3 = LUT6 > LUT1 > LUT5 > LUT4 = LUT7.$$

Table 4. Distribution of criteria subclasses according to agricultural land-use types.

Land-use type	Criteria subclasses					
	a	*b*	*c*	*d*	*e*	*j*
LUT1	620–720, 720–820, >820 m	0–3, 3–10%	FA, FN, FS, FE, FW	I, II, III	*e*1	PA
LUT2	520–620, 620–720 m	0–3, 3–10, 10–20%	FS, FE	III, IV	*e*1, *e*2	PA
LUT3	520–620, 620–720, 720–820 m	0–3, 3–10, 10–20%	FN, FE	III, IV	*e*1, *e*2	PA
LUT4	520–620 m	0–3%	FA, FS, FE	I, II	*e*1	PA
LUT5	520–620, 620–720, 720–820, >820 m	10–20, 20–30, 30–50, >50%	FA, FN, FS, FE, FW	VI, VII, VIII	*e*3, *e*4	PUA
LUT6	520–620, 620–720 m	0–3, 3–10%	FA, FN, FS, FE, FW	III, IV	*e*1, *e*2	PA, PUA
LUT7	720–820, >820 m	10–20, 20–30%	FA, FN, FS, FE, FW	IV, VI	*e*1, *e*2	PA, PUA
LUT8	520–620, 620–720, 720–820, >820 m	0–3, 3–10, 10–20%	FA, FN, FS, FE, FW	I, II, III, IV	*e*1, *e*2	PA

Table 5. Initial matrix: real values assigned to land-use types according to criteria.

Criteria	*a* (km^2)	*b* (km^2)	*c* (km^2)	*d* (km^2)	*e* (km^2)	*f* (count)	*g* (count)	*h* (count)	*i* (count)	*j* (km^2)	*k* (count)	*l* (count)	*m* (count)	*n* (count)	*o* (count)
LUT1	51.683	47.193	66.500	22.554	6.761	1	3	2	4	44.380	4	3	2	1	2
LUT2	54.308	60.117	36.342	26.388	33.747	4	2	5	5	44.380	5	5	4	5	4
LUT3	65.858	60.117	19.770	26.388	33.747	3	1	4	3	44.380	5	2	4	3	3
LUT4	14.718	27.445	50.573	10.592	6.761	4	2	3	3	44.380	4	4	3	2	2
LUT5	66.500	19.808	66.500	29.581	26.637	1	1	1	1	22.120	3	1	1	1	3
LUT6	54.308	47.193	66.500	26.388	33.747	4	1	4	3	66.500	4	5	3	5	2
LUT7	12.193	17.706	66.500	17.556	33.747	1	2	3	2	66.500	2	2	1	2	1
LUT8	66.500	60.117	66.500	36.980	33.747	4	1	4	3	44.380	4	4	4	3	5

Table 6. Evaluation matrix: normalized values of real values assigned to land-use types according to criteria.

Weight of criteria	4	13	7	11	11	9	1	10	3	6	12	2	5	5	1
Criteria	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*
LUT1	0.777	0.710	1.000	0.339	0.102	0.200	0.600	0.400	0.800	0.667	0.800	0.600	0.400	0.200	0.400
LUT2	0.817	0.904	0.546	0.397	0.507	0.800	0.400	1.000	1.000	0.667	1.000	1.000	0.800	1.000	0.800
LUT3	0.990	0.904	0.297	0.397	0.507	0.600	0.200	0.800	0.600	0.667	1.000	0.400	0.800	0.600	0.600
LUT4	0.221	0.413	0.760	0.159	0.102	0.800	0.400	0.600	0.600	0.667	0.800	0.800	0.600	0.400	0.400
LUT5	1.000	0.298	1.000	0.445	0.401	0.200	0.200	0.200	0.200	0.333	0.600	0.200	0.200	0.200	0.600
LUT6	0.817	0.710	1.000	0.397	0.507	0.800	0.200	0.800	0.600	1.000	0.800	1.000	0.600	1.000	0.400
LUT7	0.183	0.266	1.000	0.264	0.507	0.200	0.400	0.600	0.400	1.000	0.400	0.400	0.200	0.400	0.200
LUT8	1.000	0.904	1.000	0.556	0.507	0.800	0.200	0.800	0.600	0.667	0.800	0.800	0.800	0.600	1.000

The final outranking was obtained by considering the inverse arrangement, i.e. the number of arrows going to an alternative agricultural land-use type (an alternative being dominant over another one). In this case strong and weak preferences were considered together.

The final outranking was:

$$LUT2 > LUT8 > LUT6 > LUT3 > LUT1 > LUT5 > LUT4 > LUT7$$

When considering strong and weak preferences together, and using the ELECTRE II method to find the priorities of agricultural land-use types for the sample area, among eight land-use types, LUT2 (pistachio plantation and vineyard) was found to be the most suitable. From there the order from most suitable to least suitable was LUT8 (agricultural recreation), LUT6 (agro-forestry), LUT3 (orchard), LUT1 (field agriculture), LUT5 (afforestation for conservation), LUT4 (vegetable agriculture), and finally LUT7 (pasture), the least suitable land-use type.

Table 7. Concordance matrix.

	LUT1	LUT2	LUT3	LUT4	LUT5	LUT6	LUT7	LUT8
LUT1		–	–	0.7	0.7	–	0.7	–
LUT2	0.9		1.0	0.9	0.8	0.9	0.9	0.8
LUT3	0.9	–		0.8	0.8	0.7	0.9	–
LUT4	–	–	–		0.7	–	0.7	–
LUT5	–	–	–	–		–	0.6	–
LUT6	1.0	–	–	1.0	0.8		1.0	–
LUT7	–	–	–	–	–	–		–
LUT8	1.0	–	0.9	1.0	1.0	0.9	0.9	

Table 8. Discordance matrix.

	LUT1	LUT2	LUT3	LUT4	LUT5	LUT6	LUT7	LUT8
LUT1		–	–	0.6	0.3	–	0.4	–
LUT2	0.5		0.2	0.2	0.5	0.5	0.5	0.5
LUT3	0.7	–		0.5	0.7	0.7	0.7	–
LUT4	–	–	–		0.8	–	0.4	–
LUT5	–	–	–	–		–	0.7	–
LUT6	0.4	–	–	0.2	0.2		0.2	–
LUT7	–	–	–	–	–	–		–
LUT8	0.4	–	0.2	0.2	0.0	0.4	0.3	

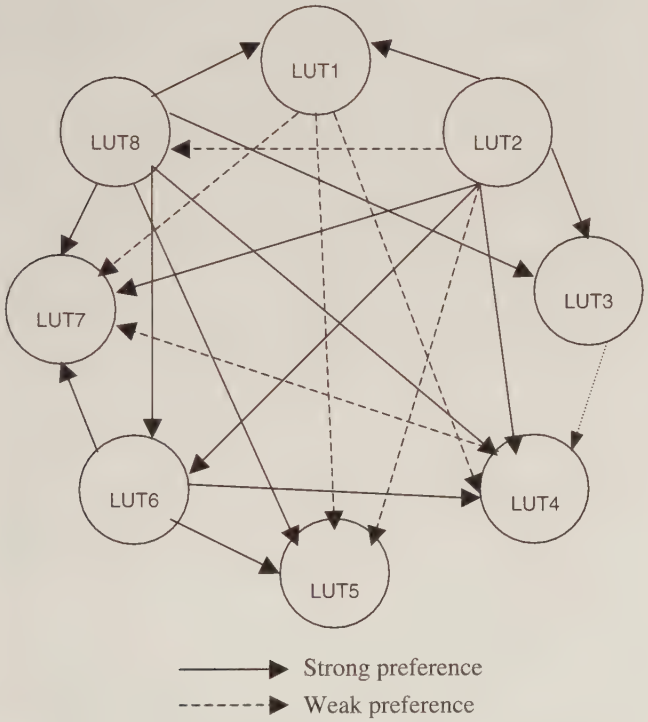

Figure 4. Preference graph according to the ELECTRE II method.

The first three most suitable land-use types (LUT2, LUT8 and LUT6) are a combination of two agricultural activities. The final outranking clearly indicated that the first three most suitable land-use types benefit from these two different aspects of agricultural activities. Thus, these land-use types at least have advantages in the context of land-use goals and politics.

Table 9. Direct arrangement of alternative agricultural land-use types.

	Length of in-paths (strong preferences)	Length of in-paths (weak preferences
1st alternative LUT2	–	–
2nd alternative LUT8	–	1
3rd alternative LUT3 and LUT6	2	–
4th alternative LUT1	3	–
5th alternative LUT5	2	2
6th alternative LUT4 and LUT7	3	2

On the other hand, LUT5 (afforestation for conservation) and LUT4 (vegetable agriculture) have a lower ranking in the sample area. Since this is an unwanted result, the planning team should reconsider the evaluation criteria, assigned weights and results.

Moreover, the relationship between these two alternative agricultural land-use types (LUT4 and LUT5) has not been established. This can be interpreted as meaning that these two land-use types are not suitable for comparison, or that they lack suitable criteria for comparison.

Additionally, the results show that the initial matrix affects results directly in the ELECTRE II method. We have noticed that the weights assigned to criteria are more influential than the values given to alternative agricultural

Table 10. Inverse arrangement of alternative agricultural land-use types.

	Length of out-paths (strong preferences)	Length of out-paths (weak preferences
1st alternative LUT2	5	2
2nd alternative LUT8	6	–
3rd alternative LUT6	4	–
4th alternative LUT1	–	3
5th alternative LUT3 and LUT4	–	1
6th alternative LUT5 and LUT7	–	–

land-use types based on the criteria. When the weights of the criteria change, the order (outranking) and relationship among alternative agricultural land-use types changes as well. Therefore, the same area could be re-evaluated with different criteria and different weights in the frame of sustainable development. In this context, criteria and their weights, which were assigned by the stakeholder group at a certain time, could vary throughout time according to the changing priorities and problems of the society and land-use policies. Nevertheless, the main criteria should contain elements that address the major aspects of sustainable development.

Conclusion

Setting priorities or ranking agricultural land-use types is a complex task in the frame of sustainable development. This study proposes a hierarchical approach and pairwise comparison in weighting of the criteria and a multicriteria analysis method for priority setting in agricultural land-use types.

In this context, both AHP and ELECTRE II methods are applicable in determining agricultural land-use priorities and can be used in the planning process. Such methods enable planners to combine their knowledge with their experience to make interpretations. Nevertheless, planners should pay special attention to the determination of criteria and assignment of weights through a consideration of the principles of sustainable development. The principles should contain elements that address the three major aspects of sustainable development: environment, economy and community.

Both AHP and ELECTRE II provide results to help with the decision-making process, rather than solving environmental and social problems directly. Both methods are quantitative in nature and rely on pairwise comparison. While traditional ways of making land-use decisions allow decision makers to make a qualitative evaluation of alternatives, the results of which can be interpreted differently, quantitative methods such as AHP and ELECTRE II support relatively objective and rational decisions and provide better information for the planners.

An application of these methods is presented for Ziyaret Stream Basin in Adiyaman, which is located in the GAP region of Turkey. While the three most important agricultural land-use types in existing land-use patterns are dry farming, pasture and vineyard, this study proposed pistachio plantation–vineyard, agricultural recreation and agro-forestry as the first three agricultural land-use types. These proposed agricultural land-use priorities will be considered in rural planning that is carried out by GAP Regional Development Administration, and the application of this plan will be realized by local government, which is one of the partners of this study.

Hopefully, this study will be a model for agricultural land-use studies in other areas of the GAP region, and will be integrated into several planning studies in the context of the GAP master plan.

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Proposal for a more efficient subsidy system for organic farming: Potential use of the tax system within the European Union

Enno Bahrs*

Institute of Agricultural Economics, University of Göttingen, Platz der Göttinger Sieben 5 D 37073 Göttingen, Germany.
*Corresponding author: ebahrs@gwdg.de

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Abstract

Agricultural enterprises that are run on ecological principles receive, in some countries, higher levels of financial support from the European Union (EU) than other agricultural businesses. The aim is to provide an incentive for businesses to adopt organic farming systems, a change desired by both politicians and society. However, with a fixed system of support payments based on land area, increasing the proportion of farms being run organically leads directly to higher costs of subsidies for the EU and the individual countries. This becomes especially true if enterprises with large land areas, high turnover and high income are converted to organic farming methods. Because financial resources within the member states are in very short supply, a modification of the current system of subsidies would seem to be necessary in the near future. The aim of any new system should be to reduce profit windfalls without making a drastic reduction in the incentive effect of the current system. At the same time, businesses that can run along these lines on a sustainable basis should be especially supported. This requires an increased level of individual assessment of the potential of the subsidized enterprises in relation to their cost–performance ratio for organic agricultural production. In this connection, a partial change to profit-based tax systems can be used as an effective instrument for co-financing. The method used to calculate profits for tax purposes, which varies from state to state, can be used to assess the performance and success of the organic farmer. Tax-free allowances or reductions in tax rates could be used to provide a selective subsidy method. The ability to relate subsidies to performance, thereby reducing windfall profits, is not the only advantage of using the tax system for this purpose. Another advantage is the low transaction costs. Using the example of the offsetting of profits between time periods, it will be shown here that the tax system can be used as an additional instrument for subsidization. The existing methods of subsidy can only be supported in this way, not completely substituted.

Key words: subsidy, windfall profits, performance principle, taxes on profits, offsetting of profits between time periods

Introduction

In the European Union (EU) the organic farmer is offered a wide spectrum of supporting subsidies. These include, for example, investment subsidies for individual enterprises, subsidized monitoring costs and support for training and consultancy. However, the most significant in terms of volume are the current land-area premiums, paid according to regulation (EC) No. 1257/99. Different premiums per hectare are paid according to the country concerned and the type of agriculture practiced (grazing, arable, market gardening or long-term crop). If you ignore the time period for changing over to organic farming, the premiums generally have a constant level which is unrelated to the success of the business. In this way there is no support related to individual breakeven performance or marginal costs. Thus the potential of this kind of subsidy to create windfall profits can be very high (Fig. 1). If the aim is to have a large quantity and variety of land farmed under organic methods, then a unified, cost-orientated subsidy must also attract enterprises for which conversion costs (U) are high (marginal cost curve). Also, the steeper the marginal cost curve,

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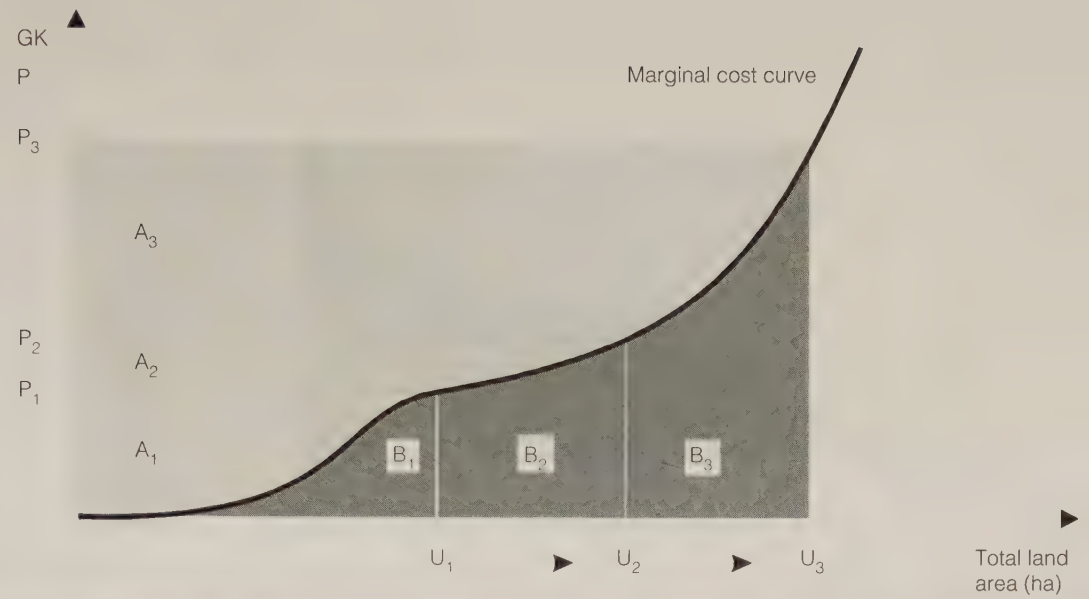

Figure 1. Organically farmed land area, state payments and the effects on income using a standardized premium. GK, Marginal cost; P, level of the premium; U, land area; A, additional income for the farmers; A + B, total of state payments.

the higher the level to which the premium must be increased in order to induce high levels of conversion (see Fig. 1, from Nieberg and Strohm-Lömpcke[1]; the increase from P_2 to P_3). At the same time, however, there is a corresponding increase in windfall profits for enterprises with low conversion costs.

This is not an efficient use of the funds available for subsidies. Despite the probable scarcity of money for subsidies in the future, there is a strong political desire to increase the levels of organic farming. With this in mind, a higher level of efficiency in the use of subsidies is clearly an important aim. The system of subsidies based on land area, which has been preferred up to now, will soon reach the limit if organic farming increases. Although the CAP (Common Agricultural Policy of the EU) reform provides some opportunities to increase the budget for subsidizing organic farming (national envelope, modulation), most of the member countries have stated that they will not increase their budgets for land-area premiums to any great extent. Because of this, the budgets could become short in the near future. Therefore, windfall effects should be reduced through an appropriate variation in premiums in which an individual subsidy is paid according to costs and performance (see Fig. 2, from Nieberg and Strohm-Lömpcke[1]). In this way, the converted land area could be increased using the same subsidy budget, or the current area of subsidized land could be maintained with a lower budget.

However, variable subsidies require a knowledge of the individual marginal costs of the farmer in question. Because these marginal costs can only be determined by methods that result in high administration costs, which more than outweigh the advantages of variable subsidies, this option has not yet been put into practice. This is where the tax system could be very helpful. Because the determination of tax is largely based on the performance of the taxpayer, the tax system could be suitable as a supporting method for subsidizing organic farming. In this way, the tax system and its regulations for calculating profits (as a performance indicator) would not only function as a normal part of the financial system, but would also be used to achieve a specific economic goal.

Suitability of the tax system as an instrument of subsidies

The financial support of organic farming from the specific perspective of the tax system has seldom been discussed up to now. The tax system, especially the profit-based taxes (income tax and corporation tax), offer ideal starting points to reflect the individual performance of the enterprise manager or the potential profitability of the business, and thus to subsidize or make charges. In addition, the tax system offers many instruments whereby businesses with low or fluctuating profits can be supported, either in the long term or temporarily. These include freedom from taxation, adjustment of taxable income or profits, tax-free allowances or tariff variations. Measures with risk-reducing effects are also possible, as is achieved with the land area premium.

The tax system is especially suitable as a subsidization instrument for agriculture, and therefore also for organic farming. One reason for this is the special position of agriculture in European (global) tax systems (see also EFAC[2]). Agriculture is, in many cases, the only sector of the economy with its own special regulations for calculating profit and its taxation, calculating assets, taxation on business capital (e.g., inheritance tax and land tax) and also consumption taxes (value-added tax and fuel tax). These characteristics enable the specific subsidization of

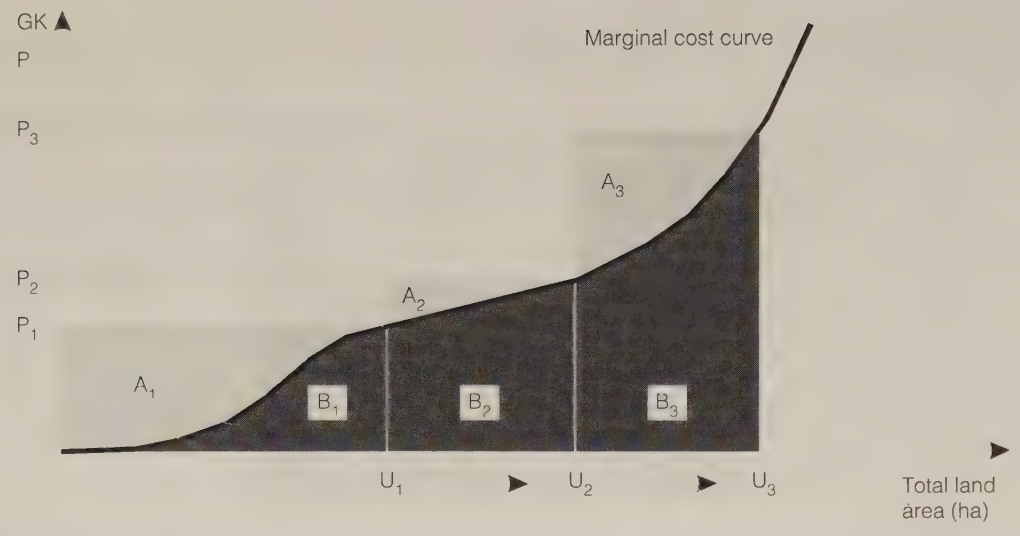

Figure 2. Organically farmed land area, state payments and the effects on income using a variable premium. GK, Marginal cost; P, level of the premium; U, land area; A, additional income for the farmers; A + B, total of state payments.

agriculture using the tax system, without causing problems due to overlap with other sectors. Because the tax system has a high level of computerization, organic farming is suitable for specific support within the agricultural tax sphere, as long as a high degree of separation from situations not qualifying for subsidies can be achieved. Organic farming can easily be defined on the basis of EU regulations (see also, for example, regulation (EC) No. 2092/91). For this reason it can be expected that transaction costs for the administration or payment of tax subsidies will not be high. This is an important advantage of the tax system in comparison, for example, to the tendering procedure also in discussion for environmental subsidies, which is seen theoretically as an efficient instrument for subsidization but can cause high transaction costs[3].

An extension or modification of subsidies for organic farming using the tax system is compatible in many ways, including the political perspective, with the concept of the ecological tax reforms currently being forced into law by many governments in the EU. In most EU countries the tax system does not serve only a fiscal purpose. On the contrary, it is often used as an instrument for steering the economy. Thus, the various profit-based tax systems include many forms of economic concession. There are general concessions in income tax systems, for example the transfer of profits on disposals to other capital assets. An example of a special concession in the taxation of agriculture is the lumping together of income from various agricultural activities when calculating taxable profits.

The legal basis for subsidizing organic farming via the tax system is not currently disputed. There are several main reasons for this. The subsidy is already in place and being distributed via the land-area premium. This, among other reasons, can be justified in terms of the favorable production of collective goods[4]. In particular, the collective good in this case is the ecological service that results from protecting the land and other natural resources. Therefore the fixed system of support payments based on land area will be needed in the future. But the windfall profits inside this system should be reduced by using the possibilities of profit taxes. So profit taxes should substitute parts of the existing system. Using the tax system as a method of distributing subsidies is meaningful if it is more efficient than the current system. In this case, efficient means that more organically used farm land could be subsidized with a given budget (especially in countries with intensively used farm land).

At this point it is of interest to look at the preconditions that must exist for using the tax system to distribute subsidies, the effects that can thus be achieved and the factors these effects depend on. These questions will be discussed in the following example, which uses an instrument of the tax system.

Results

An example of the effects of using tax instruments to subsidize businesses: the offsetting of profits between time periods

The offsetting of profits between time periods is a way of influencing the calculation of taxable profits. Using this method, the income from agriculture and forestry is not determined on a calendar year basis, but using an average value over a number of calendar years. Offsetting of profits between time periods functions like a simultaneous loss compensation and loss carry-over (with past periods). The current profit is offset by past results. The effect, however, is determined by the arithmetic averaging of the profit over multiple years.

Current profit tax principle:

$$T_t = \mathrm{PR}_t \times \mathrm{RA}_t$$

Table 1. Expected values of the annual tax savings in Euros (€) through the offsetting of profits between time periods for varying, normally distributed, annual agricultural incomes, using the coefficient of variation in annual incomes and the duration of the period of profit offsetting. Calculation based on the German income tax tariff 2003.[1]

Annual income in Euros (€)	Coefficient of variation								
	1.5			1			0.5		
	Period of profit offsetting			Period of profit offsetting			Period of profit offsetting		
	5 years	3 years	2 years	5 years	3 years	2 years	5 years	3 years	2 years
120,000	3027	2285	1531	2143	1772	1281	464	444	383
90,000	2957	2219	1484	2170	1763	1261	578	534	440
60,000	2777	2070	1382	2137	1692	1192	795	675	515
30,000	2030	1531	1036	1497	1191	843	534	451	343
10,000	642	489	337	475	369	259	214	175	127

[1] In some countries the taxable income is calculated on the pro rata basis of two financial years which differ from the calendar year (e.g., in Germany). An offsetting of profits between time periods already exists, the effect of which, however, is relatively weak. In these cases the potential subsidy must be adjusted to take into account the existing tax advantage.

Offsetting of profits between time periods:

$$T_t = \frac{PR_t + PR_{t-1} + PR_{t-2} + PR_{t-N}}{N+1} \times RA_t$$

where T_t is tax due at time t; PR_t is taxable profit at time t; and RA_t is the progressive tax rate at time t.

The effect of this instrument results, first, from its weakening of the progressive effect of the tax tariff as used in most European countries. With a progressive tariff, the average tax burden increases as the taxable income increases. In some countries (e.g., Austria) a staggered progressive tariff is used, with which the tariff increases in large steps when certain income limits are reached, whereas in Germany, for example, a linear-progressive tariff is used, which increases continuously (or in very small increments). Secondly, the commonly provided tax-free allowance can be used more efficiently. In years without profit, or with low profit, the tax-free allowance would otherwise be left partly or completely unclaimed. The offsetting of profits between time periods as a subsidizing tax instrument is thus especially geared towards businesses with widely fluctuating profits. Farmers are normally averse to risk. They would be likely to place a high value on the offsetting of profits between time periods in connection with organic farming, a production method normally associated with higher risks.

The effects of the offsetting of profits between time periods in the context of income-tax tariffs can be demonstrated using a simulation. The expected value (and thus the distribution function) of the annual tax savings can be calculated by simulating annual fluctuations and the corresponding income levels. The tax due with and without offsetting of profits between time periods can be calculated on the basis of normally distributed annual incomes from agriculture with the help of a risk analysis tool in the form of an Excel add-in. Examples of such risk analysis tools are @risk (© Palisade) or Simetar (Simulation with Excel to analyze risk, © TAMU Texas, USA). The basis for the simulation in each case is 1000 iterations using the Latin Hypercube Methodic[5]. Thus the level of iterations compared with the Monte Carlo Simulation can be reduced significantly. The two results can then be compared. The starting point is a total taxable income derived entirely from agriculture. If other income sources are included, the basic procedure remains the same. However, the effect will be somewhat damped. The difference is the tax-saving potential. In the course of the simulation, the expected value (μ), the coefficient of variation (σ) and the time span over which the offsetting of profits is permitted can be varied so that the effect becomes clear (Table 1).

Table 1 shows that the expected value of tax savings increases when the coefficient of variation of the annual income increases, and also when the period over which the profits are offset increases. With a 3-year profit offsetting period, an expected annual income of €10,000 p.a. and a coefficient of variation of 0.5, the expected annual tax saving potential is only €175. If the expected annual income is €120,000 and a coefficient of variation of 1.5 with a 5-year profit offsetting period are assumed, then the tax saving potential, i.e. the subsidy, increases to over €3000 annually. (According to the test farm survey of over 200 organic farms in recent years the average organic farming enterprise in Germany made an annual profit of between €25,000 and €30,000[6].) This shows the effect of the standard deviation (coefficient of variation) particularly clearly. Increasing the profit offsetting interval beyond 5 years causes very little further increase in the expected values. Depending on the income actually realized in successive years, the individual annual savings may be above or below the expected value. For example, according to Table 1, with an expected annual income of €90,000 and

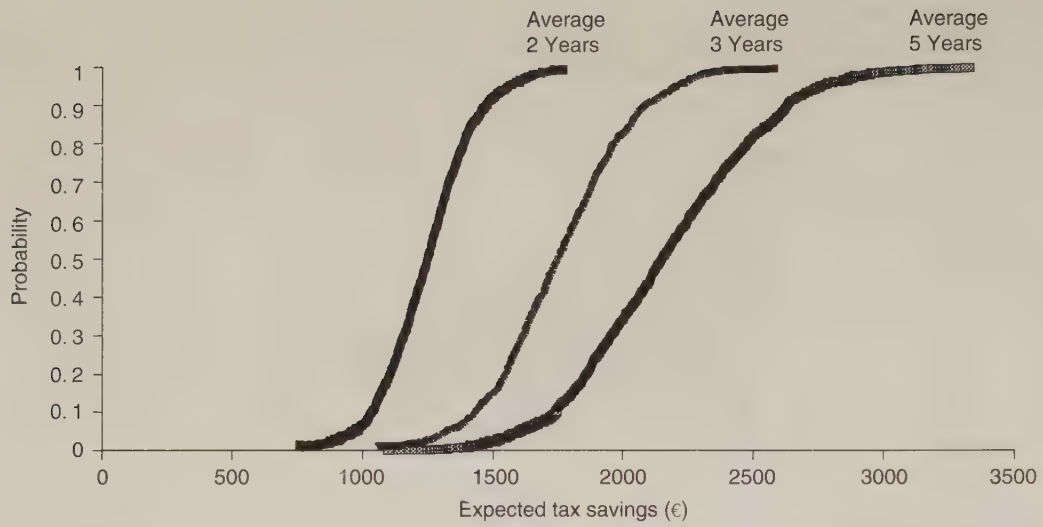

Figure 3. Distribution function of the expected tax savings in Euros (€) through profit offsetting over several years according to a simulation of normally distributed annual incomes with an expected value of €90,000 and a corresponding standard deviation. Based on the German income tax tariff 2003.

Table 2. Comparison of fluctuations in yields and prices of organically and conventionally produced crops (averages for the financial years 1998–2003). Calculation based on the *Agri-food Policy Report*.[6]

	Coefficient of variation[1]: yield		Coefficient of variation[1]: price	
	Organic farming	**Conventional**	**Organic farming**	**Conventional**
Winter wheat	0.09	0.03	0.17	0.07
Winter rye	0.11	0.06	0.12	0.11
Winter barley	0.08	0.04	0.06	0.09
Rape	0.37	0.06	0.19	0.12
Potatoes	0.13	0.10	0.11	0.12

[1] The individual variation coefficients could be much higher, because the data used in the report were already averaged from many hundreds of test enterprises. Despite this, the significant difference between organic and conventional farming is clear even on the basis of these aggregated data.

a coefficient of variation of 1.0 the expected tax savings potential is €2170 (5-year period) or €1763 (3-year period). However, as shown in Figure 3, the annual subsidy can, in individual cases, rise to over €3000 or fall to less than €1500, depending on the actual income and income fluctuation in the relevant time period. In addition, there is a first-grade stochastic dominance between the distribution functions of the various profit offsetting periods[7], so that increasing the period up to 5 years results in a significantly higher tax subsidy.

Discussion

From the above example it is clear that the level of subsidy depends not only on the level of income, but also on the extent of the fluctuations in annual income and on the length of the period in which the offsetting of profits is allowed (e.g., 2, 3 or 5 years). Greater fluctuations in income and profit can be expected in organic farming than in conventional farming, so that offsetting of profits between time periods is of particular use in subsidizing organic enterprises. An evaluation of the *Agri-food Policy Report* (BMVEL[6]) in relation to the price and yield fluctuations in organic and conventionally managed farm enterprises makes this clear. These price and yield fluctuations in the two farming systems can be compared with each other using the coefficient of variation (σ/μ) as a standard of comparison. Table 2 shows that organic farming often has a coefficient of variation 2–6 times higher than that of conventional farming (taking into account that the individual prices and yields can not be correlated with −1).

In organic farming there are even some years with complete crop failures, which must be included in the calculation. The resulting very small or negative income leads to tax rebates where offsetting of profits between time periods is in use, so that in times of low profits, or losses, the tax system provides help in making the organic system viable and, depending on the administrative speed of the tax system, provides a boost to cash flow.

Further advantages and disadvantages of offsetting profits between time periods as a tax instrument

The tax instrument described above has a reduced effect, or no effect at all, when either the tax tariff in use is not progressive (see, for example, the Norwegian system, or general reflections on flat-rate tax, e.g., Hall and Rabushka[8]), there is no tax-free allowance, or where taxation is carried out on the basis of calculating a flat-rate income for the business. This means, in particular, that this method of subsidization is not usually suitable for limited companies (corporations) because in many countries they are subject to proportional taxation without a tax-free basic allowance. However, the percentage of farms in European countries run as limited companies is generally small. In addition, this instrument is less than ideal for countries where the majority of agricultural businesses calculate their profits wholly or partly using a flat-rate system, in which the basis for assessment has little or no fluctuation (e.g., Austria).

The instrument also has a reduced or non-existent effect if the business in question fails to make a profit, or makes only a minimal profit. Many organic farming enterprises have a relatively small turnover and income[6]. Here one could easily ask the question whether these businesses should receive full subsidies in the long term. Farmers who are not able to produce adequate income from organic farming will not be able to continue with it on a sustainable basis, and will therefore not become sustained producers of collective goods (organically used land). But specific aspects in various countries must be taken into account, for example in Austria. Here tourism and agriculture are closely linked, so that farming alone does not have to provide the main source of income.

The farmers who should be subsidized are those who are able to produce collective goods on a sustainable basis. That means providing adequate income for their own family. Therefore this disadvantage of the instrument can also be seen as an advantage. The tax system can be used to select enterprises that are suitable for receiving subsidies, in that those with consistently low or negative income will not be subsidized. The tax system in general, and the offsetting of profits between time periods in particular, are therefore especially good subsidy methods. If there is no income from organic farming, there can also be no tax saving through the offsetting of profits between time periods. In this case, the tax system subsidizes only those farmers who remain consistently in the system and, after perhaps making a loss when starting or in occasional years, are able to run their enterprise profitably.

Additionally, offsetting of profits between time periods does not subsidize farmers who regularly produce very high incomes from organic farming with little fluctuation. These taxpayers will reach the highest level of the tax tariff on a continuous basis. Profit offsetting measures will have no further effect on the total tax paid. It is questionable as to whether these farmers should be subsidized at all. They are clearly in a position to achieve the aims of organic farming without receiving subsidies. In all probability these businesses have such low marginal costs, and high enough margins from the production of organic goods (and possibly collective goods), that a subsidy would be obsolete. This is also a case where windfall profits would clearly be reduced. This characteristic can also be seen as a benefit of using the tax system for the distribution of subsidies.

A further advantage of the tax system is that a subsidy based on tax which can be influenced by individual performance reduces the potential of land premiums being passed on to the landowner (for example, see Fuchs[9]). A partial passing on of land premiums can otherwise be reckoned with in the future if organic farming becomes well established in individual regions, and markets for certain land become dominant. In addition, subsidization via the tax system has the advantage that it is not directly related to production. Therefore a higher production efficiency in comparison to the use of price or land-area subsidies is likely.

Conclusion

The single example discussed above of offsetting profits between time periods shows the potential of the tax system for a more efficient method of subsidizing organic farming. However, the subsidy amounts shown in Table 1, make it clear that tax subsidies cannot completely replace the existing system based on land area. Subsidies of, for example, €2000–€3000 annually, or even less, are in many cases too little, so that tax subsidies can only be used to support the current land-area subsidy and thus function as a co-instrument for the land-area subsidy or other subsidy instruments. Even if the level of subsidies for individual enterprises were to be reduced in the future, subsidy levels achievable using the instrument of offsetting profits between time periods would be too low in the EU to provide convincing motivation for the use of organic farming methods.

However, on the topic of co-subsidizing organic farming using the tax system. there are further legal factors to consider. The co-financing of the EU and its member countries according to regulation (EC) No. 2092/91 would be more difficult. Up to now, the subsidy on the basis of the land-area premium has been easy to predict and has had little fluctuation. With tax subsidies this would be rather different. Incomes fluctuate annually, causing a similar fluctuation in the budget required for subsidies. This would have to be agreed within the EU and appropriate legislation would have to be introduced. Secondly, the finance ministers in the individual countries would have to cope with fluctuating subsidy volumes in their budget calculations. The generally preferred budget stability, which makes for easier planning, would be negatively affected. Nevertheless, the subsidy budget is so small in relation to

the total household that this factor should be of minor importance.

Agreement on profit-based tax subsidies would also be more difficult in countries where such taxes are collected simultaneously by multiple tax authorities. This would be the case, for example in the USA, where profit-based taxes can be collected separately by the federal government, the states and, sometimes, also the local authorities (e.g., Federal Individual Income Tax, State or Local Income Tax). In these countries agreements on tax subsidies would also have to be made between the various tax authorities.

Finally, a system of tax-based subsidies can be communicated efficiently, so that it would be accepted and knowingly taken up. To be a success, the subsidy must be regarded by farmers as a convincing argument for switching over to organic farming. Tax subsidies should, in addition to providing a motivation to change over to organic farming methods, provide an equal motivation to stick to with these methods[10]. With this in mind, the effect on incomes would need to be presented in a way that is easy to understand. Farmers should not have to employ the services of a tax accountant in order to make sense of the subsidy.

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Consumer perceptions and demand for organic food in Australia: Focus group discussions

Hui-Shung Chang[1,*] and Lydia Zepeda[2]

[1]University of New England, School of Economics, Armidale NSW 2351, Australia.
[2]University of Wisconsin-Madison, Department of Consumer Science, Madison, WI 53705, USA.
*Corresponding author: hchang@une.edu.au

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Abstract

In Australia, the retail value of organic food production was estimated at A$250 million, with farm-gate value at around A$90 million and exports at around A$40 million, in 2002. The current share of organic sales in total food sales in Australia is about 1%. The growth rate in organic production was forecast to continue at 10–30% per annum. Despite the positive outlook, there are consumer concerns about product recognition and product integrity. To understand how demand for organic products is changing, it is important to investigate consumer attitudes and knowledge about these issues. The objective of this study was to identify issues that may hinder or promote demand. Given the qualitative nature of these issues, we used a focus group study to probe consumers. While focus group results are a qualitative approach and not intended to be generalizable, the results suggest directions for future research. The participants raised concerns about the use of chemicals, the treatment of farm animals and the environmental impact of food production. Organic food consumers were found to be more knowledgeable about organic foods, as well as being more tolerant of higher prices and inaccessibility. The results also suggest that increasing consumers' awareness of organic farming and certification, as well as the availability of organic foods, may be the most effective way of moving organic foods into mainstream.

Key words: consumer attitudes, focus group methodology, organic food

Introduction

The demand for organic products worldwide has expanded rapidly, boosted by the heightened awareness of environmental problems, health concerns, the recent series of highly publicized food scares and the debate over genetically modified (GM) foods[1–4]. Promotion by mainstream retailers and major food manufacturers as they move into organic product lines has also been a contributing factor to demand growth. Worldwide demand for organic foods was estimated at $US23 billion in 2002[4] and growth at around 10–20% per annum in the next few years, with sales reaching $US29–31 billion in 2005[5].

In Australia, the retail value of organic food production in 2002 was estimated to be worth A$250 million, with farm-gate value at around A$90 million and exports at around A$40 million[6]. The current share of organic sales out of total food sales in Australia is about 1%, compared with about 3% in the United States[7,8]. The growth rate in organic production was forecast to continue at 10–30% per annum, with the strongest growth in beef, milk and horticulture[6]. Australia also imports some organic products, worth in the order of A$5 million annually[9]. Despite the positive outlook, there are recognized problems facing the Australian organic industry in terms of consumer confusion over organic certification and product recognition, and misleading claims and advertising[10,11]. Limited product range, high price premiums and lack of availability of organic foods in conventional supermarkets are also thought to be important factors limiting demand[9,12]. To understand demand for organic products, these issues have to be investigated. Key research questions are: Who are the organic consumers? Why do they buy organic? Are they representative shoppers or a fringe niche? How do consumers feel about the price premiums generally required of organic foods? And how important is organic certification to consumer confidence?

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The objective of this study was to answer these questions via a focus group study. A focus group study was chosen because it is an appropriate method to probe consumer attitudes and knowledge. Focus group methodology is not designed to be representative, but stratified in order to target particular groups. Given the nature of our research questions, we needed to target organic shoppers. For the sake of comparison, we also needed to include a group of conventional shoppers, as well as a group of people who grow their own food. Because conventional shoppers are the predominant consumers, the study included two groups of conventional shoppers, one group of organic food shoppers and one group of consumers who garden.

The Australian Organic Market, Standards and Certification

Despite the fact that Australia has the world's largest organic area (mostly pasture and range), the Australian organic industry is rather small in terms of the number of organic farmers and the volume of outputs, compared to conventional production. The number of certified organic farmers nationally was estimated to be between 2000 and 2200 in 2003[13], making up about 1% of the total number of farmers and 1.6% of total agricultural land in Australia.

The bulk of organic food (about 80%) continues to be sold through specialty shops and supermarkets[14,15]. There are also a small number of farmers' markets, home deliveries, box schemes, and Community Supported Agriculture (CSA) projects operating around the country[16]. There is evidence that both supermarket sales and farmers' markets are experiencing growth in Australia, similar to the developments in the United States and other parts of the world[15].

Organic production generally describes farming practices that emphasize environmental sustainability and avoid the use of synthetic fertilizers and chemicals. The aim of organic certification is to help consumers to distinguish organically produced products from conventionally produced products with specific labels, hence protecting consumers against fraudulent and unsubstantiated product claims[17]. Australia, the United States, the European Union and Japan all have their own national standards for organic certification, with specific production requirements. These standards are deemed equivalent to one another in major aspects[18]. In Australia, organic agriculture is defined in the Australian National Standard for Organic and Biodynamic Produce[17] and certification is administered by the Australian Quarantine and Inspection Service (AQIS) under the auspices of the Organic and Biodynamic Program. It is based on a third-party inspection/certification model, whereby production, processing and labeling of organic produce are overseen by AQIS-accredited certifying organizations. The Australian National Standard, which was developed in 1992, applies only to exports. This means that although it is illegal to export a product labeled as 'organic' without proper certification, there is no such regulation on organic products (including imports) that are sold in the domestic market[19,20]. As such, products that claim to be organic or carry an organic label in Australia may not necessarily meet the National Standard or have been 'certified'. Currently, Australia has seven AQIS-accredited organic or biodynamic certification organizations[21]. They are:

- Bio-Dynamic Research Institute (BDRI) with the Demeter label
- National Association for Sustainable Agriculture Australia (NASAA), accredited by IFOAM and USDA
- Australian Certified Organic Pty Ltd (ACO)/Biological Farmers of Australia (BFA), accredited by IFOAM and USDA
- Tasmanian Organic Producers (TOP)
- Organic Food Chain of Australia (OFC)
- Organic Growers of Australia (OGA)
- Safe Food Queensland (SFQ).

These certification organizations conduct physical inspections of farms, storage and transport facilities, processors, manufacturers, input suppliers and other operators involved in the supply chain. Once certified, farmers can use the certifying organization's label and certification mark on their produce. There are two levels of certification: in-conversion and certified organic. 'Certified in-conversion' means that the produce has been produced in compliance with the organic standard for at least a year after admission to the certification program. A produce can become 'certified organic' if all requirements are met for at least 3 years.

Previous Consumer Research in Australia

Research by Wynen[22] indicates that the funds spent on organic research in Australia are much less than the amount collected from organic farmers and matched with Commonwealth contributions. Among the research that has been conducted in Australia, organic food demand and income have been shown to be linked, but no clear link appeared with age, education or gender[4]. Obstacles to organic demand included: availability, cost, quality and unclear labeling[4]. Premiums for organic foods range from 50 to 75%[4]. Previous investigation of consumer motivation has focused on metropolitan areas of Queensland and Victoria[23–25].

Focus group research in southern metropolitan Queensland revealed consumer confusion about organics, related to lack of knowledge and trust, a need for information and too many certification logos[23]. Factors that deterred consumers' decisions to buy organic were the high price of organic foods, lack of income, the lack of availability of organic foods, inconvenience and high search cost. From a marketing perspective, Turnbull[23] concluded that demand

could be increased if the price was lowered, the availability increased and presentation improved. From a policy perspective, she concluded that the key to increasing demand were: standardizing certification procedures, labels and logos; enhanced information and education programs about organic foods; and government assistance in converting to organic production.

In another study, focus group research was carried out in metropolitan Queensland and Victoria and used to design a national survey[24]. The focus groups did not find a clear linkage between concern about the environment, health and other issues and organic food consumption. However, the national survey did find that consumers of organic foods were slightly more concerned than conventional shoppers about health, animal welfare, environmental protection, weight control, fitness and political values. This discrepancy between the focus groups and the national survey is probably explained by sample size. The national survey revealed that both conventional and organic shoppers were highly concerned about these issues, but with a sample of 1200, it was possible to discern significant differences in the levels of concern. However, the in-depth nature of the focus groups did identify barriers that seemed to moderate the extent to which consumers acted on these concerns. The primary barriers were availability, convenience and cost.

Focus Group Research and the Focus Groups

A focus group is a carefully planned discussion designed to obtain participants' perceptions on a well-defined area of interest in a nonthreatening environment. It is typically comprised of 7–10 people who are purposely selected because they have certain characteristics in common that relate to the topic of the focus group study. Because of this selection process and the sample size, the focus groups do not constitute a random sample, are not intended to be representative of the general population, and the results are not suitable for making inferences or predictions[26].

In general, the focus group is repeated several times with different people to obtain diverse viewpoints on a subject. It is not designed to reach consensus. Normally, it starts with 3–4 groups and may be continued until theoretical saturation is reached, i.e., no more new information is received[26]. Although a focus group study is often used as a tool for aiding survey design, it is being used increasingly as a tool for qualitative research, particularly in social science and marketing research[27].

In this research, a focus group study was conducted in Armidale, New South Wales (NSW). Armidale is a university town, home of the University of New England, with 22,000 residents. It is located 170 km inland, in an agricultural region about halfway between Sydney and Brisbane. Armidale was chosen in part because it is both a potential major producer and consumer of organic foods, and in part because we were interested in assessing the opportunity for the development of an organic sector in rural Australia. The typical organic consumer is thought to be urban[4]; however, it may be that this is driven by availability rather than demand. Thus, one reason for investigating rural consumers was to examine whether availability is a barrier, and whether their attitudes towards organic food are similar to those of urban consumers.

Altogether there were 36 participants in four different groups. The numbers of participants in each group varied from seven to ten. There were nine and ten participants, respectively, in two groups of non-organic consumers, seven in a session made up of mostly organic food consumers, and ten in a session for home gardeners. Due to limited supply of organic foods in the rural areas, it was of interest to find out the extent to which home-grown foods meet some of the demand for organic food. This design enabled us to investigate more diverse views and to compare results between groups. A summary of the socio-demographics of the focus groups is provided in Table 1. Compared to NSW/Australia, the focus groups were generally older, more educated and with higher incomes.

The objective of the focus group study was to find out how rural consumers feel about food consumption in general, and how they feel about organic foods in particular, as well as how much they know about organic food. We also wanted to know what factors impact food choices, whether conventional or organic foods. In addition, we asked both organic and conventional shoppers what they knew about organic certification, what organic foods people bought and why, and how they perceived the price premium for organic food, in order to identify differences in their perceptions and motivations.

Question 1. What are the Most Important Characteristics of Food that You Pay Attention to When You go Grocery Shopping?

The answers to this question varied depending on the socio-demographics of the participants, such as whether a family member had a health problem or food allergy, whether the family had young children, whether they were vegetarians and whether they were constrained by budget. Reponses are summarized in Table 2. Overall, the most important characteristics of food that people pay attention to are: sensory appeal (taste, flavor, texture, smell, look), freshness, variety, nutrition, costs, convenience and serving size, where the food come from, and how the food is produced. For those families experiencing health problems (e.g., diabetes) or food allergies/sensitivities (e.g., monosodium glutamate the (MSG) sensitivity), they needed to know what was in their food and they often checked nutrition labels (especially low fat, low sugar, low salt, and MSG-free).

Table 1. Socio-demographic summary of focus group participants.

Marital status	
Single	9
Married	12
Divorced	8
De facto (living together as man and wife but not married)	4
Others	3
Highest degree obtained	
PhD	9
Masters	5
Bachelor	9
Trade certificate/diploma	5
High school	6
Others	2
Employed	
Yes	34
No	2
Occupation	
University lecturers	8
Researchers	2
AA	3
Students	6
IT	2
Others (non-UNE employees)	15
Ethnicity/race	
/Caucasian	36
Primary food shopper in household	
Yes	28
Shared	5
No answer	3
Dietary restrictions in household	
Yes	16
No	20
Age of participant	
20–29	2
30–39	6
40–49	15
50–59	11
60+	2
Sex of participant	
Female	23
Male	13
Children under 18 living in household	
Yes	13
No	23
Annual household income (A$)	
<30,000	7
30,000–59,999	15
60,000–89,999	3
90,000+	7
NA	4
Have you ever bought organic food?	
Yes	30
No	5
Don't know	1
When was the first time?	
More than 1 year ago	4
More than 3 years ago	3
More than 5 years ago	3
More than 10 years ago	18
No answer/forgotten	8
Where?	
Armidale	2
Elsewhere	23
No answer	11
How often do you purchase organic?	
Weekly/bi-weekly	14
Monthly	2
Few times a year	7
Never	3
No answer	10
From where do you buy organic?	
Supermarkets	Most had multiple answers
Farmers' markets	
Food co-ops	
Health food stores	
Home grown	

AA, administrative assistant; IT, information technology; UNE, University of New England.

Some emphasized their preference for organic or unprocessed foods. Others preferred seasonal, locally grown or Australian-made foods. Quite a few participants grew their own vegetables, because they have more flavor and fewer chemicals. Some were hesitant to use the term 'organic' to describe their home gardens because they are not sure about the manure they used.

For those who identified themselves as organic consumers, personal health, environmental concerns, animal welfare and protecting small farms and rural communities were all part of the selection criteria.

> I like to look at the food, I like to smell it, and I like to taste it. With grapes, I like to taste a grape or something like that. I like to be informed too; I ask questions, where it's from and that aspect of it. And from an animal point of view, I'm interested in the welfare of the animals as well as the environment the food is coming from, so I'm pretty selective in that way. I don't really care too much about the cost because I believe the benefits and the health far outweigh that aspect in the long term, my health is more important in the long term than the short term economic gain.

For non-organic consumers, the main consideration for food choices appeared to be related to sensory appeal, especially taste and flavor. A majority of organic consumers in this study were vegetarians; therefore, nutrition was a very important consideration. It was clear that some participants had very strong views about the food they ate, while others were not so selective. From the discussions, it was also apparent that people often had conflicting goals concerning their food choice. Most organic consumers wanted to purchase as much organic food as possible, but were often constrained by budget,

Table 2. Food characteristics that participants valued.

Sensory factors	Taste
	Flavor
	Freshness
	Texture
	Appearance (color, look)
Health factors	Health
	Nutrition
	High in protein, vitamins and minerals
	Well-balanced diet and high nutritional value (especially for children)
	Low fat, low salt, low sugar, MSG-free
Lifestyle	Convenience/serving size/variety
Cost factors	Price
	Value for money
Family preferences	Something that family or children will, or like to, eat
Level of processing	As unprocessed as possible
	Minimal packaging
	As free of preservatives and additives as possible
Social/ethical concerns	Animal welfare
	Grown with minimum chemicals
	Low impact on the environment
	Does not contain genetically modified organisms
Other criteria	Produced locally or Australian made
	What is in season

MSG, monosodium glutamate.

what was available in the market or by the time that was required of them to shop around. For families with young children, the choice was often dictated by what the children would eat, rather than the nutritional content of the food or tastes and preferences of the adult shoppers. Another potential conflict was that people wanted to have a healthy lifestyle but were often either too lazy or too busy to do the right thing.

> I've got an idealistic view of what's the most important characteristics of food for me, and then I've got a practical and real, real feeling of what's the most important characteristics of food for me. I mean I'd love to eat healthy and low fat content [*one participant laughs*], all those things that you get thrown at you as a kid and right through, but for me, the ideal and the practical, I think I'm lazy, and what's the easiest, comes, oh just this time and next time I'll do better, I mean that's just the way it is.

Some also thought that a little healthy (organic) choice was not going to offset their other bad habits (such as eating fatty food or junk food, drinking or smoking) and make any difference to their health. For students, budget was the most serious constraint on food choice because of price premiums associated with organic products.

Question 2. What Does the Term Organic Mean to You?

This question was asked to find out about the participants' perceptions of 'organic', i.e., what comes to mind when they hear the word 'organic'. In general, most participants mentioned: 'free of chemicals, pesticides and residues', 'healthiness', 'wholesomeness', and associated these with the physical attributes of food products. The answers are summarized in Table 3. However, to some it means 'growing in tune with, in harmony with nature', 'ethical', 'sustainable' and 'small-scale production', which are related to the production process.

> It's something that is grown in congruence with nature, so it's sustainable. I like the ethics behind that. To me, I guess I equate organic with healthy. And probably better for you, I feel better about eating it.

To a few, it conjured up more stereotypical images of 'home grown fruit and vegetables', 'small and imperfect', 'knobby little apples, little wormy things' and 'hippies and their alternative lifestyles'. There was also some mention of genetically modified organisms (GMOs) in the discussions, that they are unnatural and go against the concept of organically grown. There was some scepticism among the participants about organic foods, especially in one group of conventional shoppers. These concerns included lack of confidence in certification and doubts about the ability to produce sufficient food without synthetic fertilizers and chemicals.

> ... I come from a long line of farmers and I can't see the difference much between super phosphate and chook poo. [*participants laugh*]. I think the word [*organic*] has been hijacked by marketing people to drop the idea that something is better for you. We'd probably be a fairly hungry world without some of these chemicals and fertilizers.

Question 3. What Does Organic Certification Mean to You?

We asked participants about organic certification, to understand how important it was in their perceptions, confidence and behavior towards organic foods. Most participants said that organic certification means labels, trademarks and logos, which, in turn, mean 'a stamp of approval' and 'some sort of guidelines, standards and regulation', and it's an important tool for building up faith and trust in the origins of the product (see Table 4 for a list of results).

> Organic certification means to me that the food has met the requirements, has been grown and stored and met the requirements of different organizations certifying it.

Table 3. How participants defined 'organic'.

Farming practices	No chemicals at all
	No pesticides, no chemical fertilizers, no hard chemical sprays
	Low or as little pesticides and chemicals as possible
	Chemical free and preservative free
	No artificial colors and flavors
	Not genetically modified
	Not adding nasty things that are going to be nasty to anything else and the surroundings
	Naturally ripened
	Grown as close to a natural process as possible
	Grown in tune or harmony with nature in sustainable communities
	Wholesomeness if grown in a sustainable way
	From the earth/clean earth/healthy soils
	Recycling of all farm materials
Standards	Commercially has been certified according to national standards and if home grown, as close to certified minimum standards as possible
Other associations	Small scale production
	Seasonal vegetables and fruit
	Home grown
	Grown locally
	Older varieties and non-hybrid
	Growing and producing produce in as old-fashioned a way as possible
	Small and imperfect
	Alternative lifestyle
	Knobby little apples, little wormy things
Product attributes	More nutritious
	Natural and healthier
	Natural and expensive
	Clean foods
Marketing ploy	A marketing term to drop the idea that something is better for you

> I understand there are several different organizations in Australia that you can get certification for and that [*word missing here*] the requirements that they're growing, and they've also undergone regular testing to make sure that people aren't cheating the system as well and just putting organic labels on inorganic food.

However, there was also some scepticism about organic farming and certification. Some cast doubt on the level of guarantee, the level of packaging, the distance of transport, the emergence of large corporate organic farms, the possibility of contamination from neighboring conventional farms, the ability of organic farming to provide food security to a growing population.

> To me, there's a difference between what I understand when I go to the shop and say this is organic. I know enough that there are always criteria that farmers have got to satisfy to have the product labelled as organic or chemical free, to be grown in this way. That's what it means to me when I see it on the label, but I guess, I would hope it to mean something more, like growing in tune with, in harmony with nature and in sustainable communities, those kind of more general and utopian kind of ideas in a way.

> From what I understand a farm can be deemed organic when neighbouring farms are not adhering to organic farming practices.

One participant commented that organic certification is about the production process, not the product; therefore, there was no guarantee that the products were not treated with chemicals after leaving the farm. There were also questions about what was required to certify that milk and meat were organic. These comments confirmed previous research findings that consumers desire more information.

> It means they are producing basically something that doesn't harm its environment or the end consumer, but I don't really know how this certification is granted, as a consumer. And in fact, I wouldn't mind finding out about that.

Question 4. What Organic Foods do You Buy? Where? And Why?

In terms of what people buy that is organic, fruit and vegetables appeared to be the main category, followed by

Table 4. How participants defined 'organic certification'.

Production standards	Some sort of standards, guidelines or regulations
	Labels, trademarks or logos
	There are two or three different levels of organic certification
	Producers follow guidelines and are being monitored by certifying bodies
	Soil testing
	Strict production guidelines
	Standards or guidelines are on production process, not product
	Probation period
	Organic farmers are routinely and randomly being tested
Consumer confidence	It is a stamp of approval
	Trust and faith
	It means that the farm and the process have been tested and meet certain criteria
	It means you have jumped through certain hoops
	It is some kind of reward to organic farmers who have done the right thing and producing smaller yields as a result
	The food has been grown without chemicals, pesticides in as natural way as possible
	It means that something is more likely to be free from harm-causing chemicals
	It gives me confidence that what you are reading about is what you are actually eating
	Certified has the least extra stuff in it
	I will choose something that is labeled as certified organic over organic
	It means it is useful and convenient (for buying decisions)
Scepticism	Obviously it has been through experts and the criteria, but I am fairly cynical about certification and the process and what it actually means
	Who checks the checkers?
	I am not convinced that it is well policed
	It's been through some form of checking process, but how far has that process been?
	Organic certification is the end product of some kind of political compromise
	The organic standard is not the best but workable
Organic label	I would go into labels as much as I could, but I don't trust them 100%
	I don't trust the label completely, but it is likely to be better than something that makes no claim to be organic
Knowledge/awareness	I don't really know what organic certification really means
	I can't remember ever having seen such a description
	Well, it means nothing to me

staples such as flour, cereals, legumes (kidney beans, lentils and cannelloni beans), pasta, milk, yoghurt, tea and coffee, and juice. Soya milk and tofu were mentioned a few times as key organic purchases because of vegetarian diet or food allergies. Although a variety of organic products were being purchased, the list was still quite limited compared with conventional foods that are available in the supermarkets. Indeed, participants tended to mention only a few things that were more readily or regularly available to them. Only two of the participants were 100% organic consumers.

In general, participants acquired organic foods from a variety of outlets, including supermarkets such as Coles, health food shops, organic specialty shops, fruit and vegetable markets, farmers' markets, home delivery, box schemes and directly from local farms or friends. Some participants also grew some of their own vegetables. 'So it's basically whereever is available'. Most organic consumers tended to hunt around for organic food in different places, but some purchased only what was available at supermarkets (Coles or Bi-Lo). Since there appeared to be limited choice for organic consumers in Armidale, what was consumed was dictated by what was available.

> I find it really hard to access. If it were more readily accessible, that would be my choice for sure.

However, there were also other considerations (Table 5). For example, organic staple foods (flour, cereals, grains) were bought because they made up a major portion of food consumed and hence were expected to be most effective in terms of avoiding chemicals. Some participants bought certain organic products because of the amount of sprays that are required if conventionally produced. Bananas, broccoli, onions and soya products are some examples given. Some bought organic foods because they tasted better. For example, organic lettuce, tomatoes and carrots were said to have lot more flavor than their conventional counterparts.

For non-organic consumers, the foods that they would consider buying organic were: fresh fruit and

Table 5. Reasons given by participants for buying or not buying organic foods.

Reasons for buying	Reasons for not buying
Healthier	Availability
To reduce having health problems later	Inconvenience
To keep away chemicals	If it is not at where I normally shop, then it won't be on my list
To avoid growth hormones and antibiotics in meats	I am lazy and wouldn't go out of my way to go and chase an organic apple across the countryside
When they are on special	I am a convenience shopper with three children
To help poor organic farmers out there	Price
Avoid allergic reactions to chemicals	Not convinced about the benefits of organic or the risks of the non-organic
Taste and flavor	Extra cost and extra effort
Environmental concerns	It is not included in my decision making criteria
As a way of making a political statement (against multinationals)	Prefer something that is grown locally and how it is grown
I am young and idealistic, so I think it would be better (for the environment) if more farms were organic	They don't look impressive
	Small
	Not fresh
As I get older, I like it cleaner	It is not a realistic way to grow food
	Don't feel the need to since we've survived all this time

vegetables (because they felt they would be unprocessed and hence more likely to be truly organic, and because conventional strawberries and tomatoes for example, were perceived as huge but with no taste); staples (flour, rice, cereals, etc.); oils (because of how they are processed); eggs (for concern over animal welfare); chickens (because of the use of growth hormones and antibiotics); and meats (because of biomagnification of chemicals in the food chain).

> I think oil, I'd like to know more about organic oil, because I remember reading something about how oil is produced, and I think it's something like detergent that goes in it, to then extract the oil, and that concerned me, so I'd like to know more about organic oil, and would consider purchasing that. And strawberries and tomatoes, I'm sick of strawberries that are really big but have no taste [*several participants laugh*], and tomatoes that are huge but floury inside or don't have much pulp or juice. So if someone could produce good quality strawberries and tomatoes that are organic and don't have to be enormous, I would buy them.

By comparing the reasons given by organic consumers for buying organic foods with the reasons given by non-organic consumers for considering purchase of certain organic foods, it is clear that they are basically the same. That is, they are all concerned about the level or concentration of chemicals in the food, flavor and animal welfare. It is interesting that concern about the environment was mentioned only once as a reason for buying organic foods, although it was indicated several times as one of the food choice criteria.

> ... we grow vegetables at home and grow them organically, so yes I've had organic at home but I don't go and buy, or I don't seek out, I mean I might if I like the look of something buy it, but I do not seek out or choose to buy organic food. I don't particularly value it. And to me I can't see the demonstrated benefit enough for the cost of it. And I don't think it's a realistic way to grow because I do not think the society can be fed by growing organically. But I would prefer to grow my own farm and grow organically because I think it's healthier. I don't like to have pesticides. It's the pesticide issue rather than herbicides or fertilizer.

Most organic consumers indicated a strong preference to get everything organic, but often felt they could not do that because these goods were simply not available in Armidale, and when they could not get organic foods, they bought conventional food. They felt they needed to be practical and flexible. This highlights an important issue facing organic consumers in rural towns such as Armidale, i.e., the availability and the quality of organic foods. For an organic consumer, the amount of effort and time that is required to meet their daily needs is tremendous, and because of the lack of supply, substitution between organic and conventional products is frequent and often necessary.

> But just because, you don't want to go running around to a hundred different places, so I tend not to shop very much, and when I do, I just run around Coles and get as much as I can.

Given the demand on people's time in a modern society, it is not hard to see why some people believe that organic is better in many aspects, but are not organic consumers—they cannot afford to shop around. Lack of availability appears to be a main deterrent for further demand. During the discussions, it became clear that supply sources were

becoming even more limited with the disappearance of home delivery services, box schemes and closing of a local produce market. Supermarkets such as Coles, on the other hand, have increasingly stocked more organic food. For non-organic consumers, since they did not seek out organic products, they were hardly aware of any supply sources of organic produce.

Question 5. Do You Think There is a Price Differential Between Organic and Non-Organic Food? Is it Justified?

Most participants agreed there is a price differential between organic and non-organic food, but most of them did not know how much. Several reasons were given for the price differential: lower yields, extra costs associated with certification, small-scale production, labor intensive (because of strict production guidelines and difficulties in controlling pests and diseases without chemicals), higher risks and scarcity (Table 6). Most participants thought the price differential was justified since it cost more to grow organic food (Table 7).

> I think there is a price difference, not as much as it used to be 10 years ago. It used to be phenomenal when I consumed in Sydney. I think now, it's probably, to me it feels like about 15% difference, and I think it is justified because I think getting back to certification and guidelines and strict regime that is required to have your soil certified and have your production costs a little bit higher to meet that standard.

Others thought it was justified because they perceived organic food as healthier, more nutritious and more delicious. Some felt it was justified because they believed organic food was more ethical or environmentally sustainable. However, one participant pointed out that although the price differential might be justified, it did not

Table 6. Reasons given by participants for a price differential between organic and non-organic foods.

Scarcity
Cost of certification
Problems in controling pests and diseases without chemicals
Lower yields
Higher risks
Small-scale production
More labor intensive
More wastage if not spraying
Organic-grown chickens need more space
It costs more to get from producer to the market
Mark-ups by middlemen/shops
Extra packaging/wrapping

Table 7. Is the price differential justified?

Yes	No/not sure
Personal benefits	It preys on people's fears
For what you get per benefits that you get	Over-priced
It is more nutritious	Ripped-off by middlemen
It is better quality	Only a certain strata of society (the middle class) can afford it
It is good for the environment	Don't know
It is more ethical	Don't think that the regulation is strict enough
It is more delicious	I don't think it is sustainable, I think it is a boutique, fashionable industry
It is healthier	No one has proven to me that it is better for me
It makes you feel good for contributing to sustainability and not contributing to soil erosions	It is a marketing thing for more profits
Growers should be rewarded for hard work	We would not be able to feed ourselves
Reflection of real costs	
It is close to the real cost of production (considering hidden costs of soil degradation in conventional farming)	
Mass production of food is a false thing (lower cost but poor quality)	
It is cheap compared to processed, packaged or take-away food	
It is cheap if environmental and social benefits are factored into	
It is cheap compared to taking vitamin supplements	
Paying higher prices now may encourage supply and eventually lowering prices	
BUT only if the growers get it	
BUT I don't think many people would be willing to pay double or triple	
Only if we can prove that organic is indeed healthier and better for the environment	
It is justified but 200% more is just too much. It should not cost as much	

necessarily imply that people would be willing, or could afford, to pay more.

> I assume that there is, I'm not sure how much it is. I notice with eggs, free-range eggs really have got a huge premium on them compared to the battery hens but I'm willing to pay that kind of premium because I know, well just ethically I wouldn't want battery eggs. I think it is justified because I've known farmers who have grown organic and I know they're not getting rich, so whatever premium they can get is justified for them. On the other hand, it's up to me to decide whether or not I'm willing to pay.

> I don't think that many people, many farmers, take into full account the cost of producing whatever you want, a kilo of wool or a kilo of wheat. The full cost of the environment, of top soil degradation, of putting [*word missing here*] chemicals on, of somewhere where you've taken those chemicals out, you're digging up countries for super phosphate so you can apply it to your soil, that has to be taken into account in the farm price. So there is a price differential, from my experience. I would only probably pay maybe twenty to thirty percent, so I think you'd find it hard to sell much volume if there's that much price premium, double or triple, I don't think many people would be willing to pay that, but I think it's justified.

Some participants thought that organic foods were elitist and only the middle class could afford them. Others argued that organic products were actually cheaper compared to processed food or fast food. They also felt they were cheaper than conventional foods if sustainability and costs of soil degradation were taken into account. Others wanted proof.

> Is it justified? Yes, if we can prove, like I'm getting in my head organic and non-organic, if we can prove that organic means healthier, better for the environment, if we can prove that it's better on our landscape as against non-organic, of course it's justified. But that, I don't know if it's just a perception with me or whether it's real, that organic is, yes, healthier, better for the environment, that non-organic is actually doing this vast damage to the environment and it's doing bad things to me too, to people. Is it justified? I don't really know.

Another point of view is that price premiums, as a result of scarcity, might be necessary in the short term in order to encourage more production, and would eventually lead to lower prices, making it more affordable to more people. Another comment worth mentioning was that 'I'd like to see the government subsidise organic farmers, help them along, make it more accessible to people'.

Concluding Remarks

A focus group study was conducted in Armidale, NSW to investigate consumer attitudes and knowledge of organic food in rural Australia. The study consisted of four focus groups and five structured questions. A group of organic shoppers was compared to two groups of conventional shoppers and a group of gardeners. All the individuals in each group were asked to identify the most important characteristics of food when shopping, what 'organic' and 'organic certification' signified to them, whether and what kind of organics food they buy, whether they thought there was a price differential for organic foods, and if it were justified.

The overall results suggest that: (1) sensory appeal is the overriding factor in food choice; (2) there are different levels of awareness and understanding of 'organic' and 'organic certification' among participants; (3) the lack of availability of organic food in rural Australia is a limiting factor in demand; (4) concerns over dietary and health restrictions motivate many organic food buyers; (5) concerns about the level or concentration of chemicals, the environment and animal welfare, as well as taste, are the same motivations behind the consumption of organic foods by organic consumers and potential motivators for non-organic consumers; and (6) both organic and non-organic consumers believe the price premium for organic food is generally justified because of higher production costs, but the differential does restrict purchasing behavior. In addition, it appeared that the market for organic food in rural towns such as Armidale may remain limited, due mainly to its short growing season and long distance from major distribution centers in Sydney, Brisbane and Melbourne.

The same questions were used in a focus group study in the US[28]. The results revealed that sensory appeal was also the primary factor in food choice among US participants. However, there was generally more understanding of 'organic' and 'organic certification', especially among organic food shoppers. Lack of familiarity, especially for organic products other than fruits and vegetables, lack of trust in organic labels, and price were the primary barriers in purchasing organic foods among US participants. The motivations were similar among the US organic shoppers: diet, health, the environment and animal welfare. One issue that an all African-American focus group raised, which was not raised either in the Australian focus groups or by the other US focus groups, was social justice. In general, the US focus groups concurred with their Australian counterparts that a price premium is justified, although a few individuals among the US groups did not agree.

Expanding upon the Australian findings, the focus group discussions revealed that consumer preferences and food choices appear to be influenced by socio-demographic factors such as income, family structure, lifestyle, dietary restrictions (due to health problems or food allergies, or

whether they are vegetarians) and some social values and beliefs. Some of these results are consistent with previous findings[1,3,29,30].

The focus groups revealed that, while organic means 'free of chemicals', 'wholesomeness' and 'sustainability' to most participants, organic certification was not as familiar to the participants. While certification is understood to involve standards, guidelines, regulations and enforcement, there was not widespread understanding, even among organic shoppers, of the different certification marks and labels. Not having a unified logo clearly adds to the consumers' confusion and lack of interest.

In terms of availability, it is clear that organic consumers would like to buy as many organic products as possible, but they are often constrained by what is available in the market and the time required to hunt around for it. As such, it is often necessary to substitute conventional food for organic food or to grow one's own produce. The latter is not a viable option for most consumers.

In terms of the price differential that exists between organic and conventionally produced foods, most participants thought it is justified because organic farming means more work and lower yields, and many felt it was also more sustainable and more ethical. Many thought price premiums are also justified because they perceived organic products to be healthier, more nutritious and more delicious. Many participants were willing to pay for the price premiums associated with organic food. However, there were some reservations. For one thing, the higher price may be unaffordable to those on low incomes (such as students). Further, some suspected that organic food was overpriced due to unscrupulous middlemen.

The focus groups suggested some differences between organic and non-organic consumers. The main difference was the set of criteria they use in choosing food. In most cases, the list of criteria was much more extensive for organic consumers than for their conventional counterparts. Consistent with findings by other researchers[1–3,29,31,32], organic consumers tended to consider the effect of their food choice on personal health, the environment, animal welfare and other social issues, while non-organic consumers tend to focus more on sensory appeal (e.g., taste and appearance). Indeed, a few non-organic participants indicated that they would like to try some organic fruit and vegetables just to see whether they tasted better than conventional food. Moreover, availability was a main constraint to increasing consumption of organic food by those who purchased organic foods. Thompson and Kidwell[33] found store choice a main factor affecting organic purchases, but this was in a metropolitan area of the US where organic foods were widely available at health food stores and a food cooperative. As with Goldman and Clancy[34], price was not the main constraint for organic shoppers. However, price and negative attitudes were the main deterrents for non-organic consumers. These findings need to be validated using larger, random samples.

If these findings hold up in a larger sample, several policy implications could be drawn. First, given the generally low levels of consumer awareness and understanding of the meaning of organic, and especially organic certification, there is a need for consumer education and information. It is clear from the focus group discussions that the skepticism over organic farming and certification, and hence negative attitudes towards organic foods, is often a result of lack of knowledge. Education and information programs, if implemented, could try to address consumer concerns over: the level of guarantee, the level of packaging and processing, the distance of transport, the emergence of large corporate organic farms, the possibility of contamination from water, air and neighboring conventional farms, and the ability of organic farming to provide food security to a growing population. Many of these concerns were also identified by other resesarch[24,35].

Secondly, consumers do have different motivations in making food choices, and often these choices are competing or conflicting. For example, the participants identified that their desire to eat healthily often competes with their desire for convenience or flavor. For them, healthy food involved more preparation, while prepared or convenience foods were viewed as quick and tasty but not healthy. Marketers could find ways to resolve these conflicts facing consumers, with products that combine both convenience and healthy ingredients.

Thirdly, while availability is the main problem for organic consumers, price is a key obstacle preventing non-organic consumers from trying organic foods. Given that higher prices of organic food are attributable partly to small-scale production and limited supplies, increasing supply and improving supply-chain coordination appear to be the major challenges facing the Australian organic industry in its attempts to increase market size. However, more research is needed to address both the demand and supply side issues in the Australian organic market.

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Garden production systems and food security in Ghana: Characteristics of traditional knowledge and management systems

Emmanuel K. Yiridoe[1,*] and Vincent M. Anchirinah[2]

[1]Associate Professor, Department of Business and Social Sciences, Nova Scotia Agricultural College, PO Box 550, Truro, Nova Scotia, B2N 5E3, Canada.
[2]Research Scientist, Socio-Economics Division, Crops Research Institute, PO Box 3785, Kumasi, Ghana.
*Corresponding author: eyiridoe@nsac.ns.ca

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Abstract

There is limited documented scientific information on garden production systems managed in developing countries, partly because both researchers and research administrators have, until recently, ignored them as legitimate areas of study, and because such production systems have been regarded as informal production activities, managed outside conventional market and economic channels. Yet in a developing country such as Ghana, these production systems are potentially able to contribute substantially to the food security and health needs of households. This study was aimed primarily at providing critical scientific information for understanding the complex web of production and management factors associated with garden production systems. A total of 300 survey responses, representing the Sudan savannah, Guinea savannah and moist deciduous forest agro-ecological zones of Ghana, were analyzed (27% of respondents were females and 73% were males). Several hypotheses from the field agriculture literature were tested to determine their relevance in garden production systems. Although, for the country as a whole, a variety of garden crops are cultivated, each agro-ecological zone concentrated on a set of four major crops, with the actual food crops differing across agro-ecological zones. The type of protective fencing used was not statistically associated with land tenure (i.e., own versus rented land) status of the gardener ($\chi^2 = 3.285$, $P = 0.4501$). Gender responsibilities in garden production and management tended to be more equally shared in the forest agro-ecology, where garden crops are cultivated for household consumption and for generating family income. In contrast, in the two savannah zones, adult males undertook a disproportionate share of activities to produce garden crops that were primarily for marketing. Valuable information on production and management exist within the traditional garden production systems studied, and range from socio-economic, agronomic and medicinal considerations in selecting garden crops and fruit trees, to ecological monitoring systems and strategies for garden management.

Key words: food security, garden production systems, Ghana, medicinal crops

Introduction

Studies in garden production systems (especially their socio-economic and management aspects) are limited[1], because of unique challenges in undertaking such research[2–4]. Niñez[3] noted that the limited knowledge about garden production systems is partly because both researchers and research administrators have, for a long time, ignored such production systems 'as a legitimate area of research'. Other challenges stem from a perception that garden production (along with urban/peri-urban agricultural) systems are managed outside conventional market and economic channels, with little data and other formal information available for research[4]. In addition, garden production systems (and urban/peri-urban agriculture) have been regarded as informal production activities[2,5], although they are a major form of economic activity and, in some urban and rural populations in developing countries, are the only source of household-grown food[2,5].

Researchers and policy-makers are increasingly acknowledging the potential role that garden production systems play in reducing food insecurity and improving overall

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well-being, especially among populations with limited resources[6,7]. During the past few decades, there have been an increasing number of national and, in particular, international initiatives to promote and support garden production[2,8]. In sub-Saharan Africa, garden production has complex economic, social, and health and nutritional importance, as well as serving as an important alternative food production and distribution system.

As the world population increases, less urban parts of Africa (and Asia) will grow the fastest, with urban and peri-urban regions projected to have the highest growth[9]. As rural populations grow, they become increasingly urbanized, while others migrate into cities. These projected changing population dynamics suggest that garden production systems could play a greater role in helping to alleviate Africa's food insecurity problems. Paradoxically, although this potential of garden production systems exists in sub-Saharan Africa[2,10,11], it is also the only region in the world with an increasing trend of a malnourished population[12]. Garden systems can produce safe, nutritious, fresh and economical food, and help sustain agro-ecosystems and the farmers who eke a living from such systems, while protecting other (natural and genetic) resources[13]. Indeed, low-income households in developing countries are more likely to consume a nutritionally healthy and balanced range of food types, depending on the biological diversity of their garden operations[2,8].

Although garden production systems in Ghana are sustained by a complex web of factors, there is little documentation and understanding of these issues. Increasing urbanization and rural population changes make for a dynamic agri-food sector, with various opportunities and potentials, yet it also has high risk. Preliminary efforts at understanding garden production in sub-Saharan Africa as a whole have examined the production potential of these systems[2]. However, less attention has been devoted to investigating the contribution of garden production systems to achieving multiple functions and economic benefits. Anecdotal evidence and perfunctory studies for Ghana suggest that gardening is of critical importance to both rural and urban households[10]. Thus, gardeners need to be well informed if they are to avoid the problems associated with garden production and realize the full potential associated with distributing and marketing garden products. For example, in a study of the Philippines, Boncodin and Campilan[8] reported that the choice of garden crops is generally influenced by the intended household use of the garden produce (e.g., food needs versus income-generating activity). Policy-makers and agricultural administrators also need information on garden production systems to guide them in making informed decisions.

This study forms part of a larger multi-disciplinary research project aimed at identifying, documenting and assessing important practices and decisions associated with garden production, management and utilization of produce, and how indigenous technical knowledge could be used in developing suitable methods for genetic resource conservation. Increased production can be facilitated through targeted extension and other support services, if the production and management characteristics of target groups of garden producers are understood. Thus, this study compared the characteristics for three agro-ecological zones with significant garden production in Ghana, namely: the Sudan savannah, the Guinea savannah, and the moist semi-deciduous forest zone. Specific objectives of this study were: (1) to identify and document the major production and management practices of garden cropping systems; (2) to assess gender roles in managing selected garden production systems and practices; (3) to compare and contrast garden production systems and practices with characteristics in conventional field agriculture, across the three agro-ecological zones; and (4) to assess the contribution of garden production systems to household food security. Furthermore, traditional medicinal uses of cultivated garden plants, as reported by survey respondents, were documented (see Appendix 1).

Garden Production Systems: A Paradigmatic Review

Researchers from various disciplinary and paradigmatic perspectives have referred to what, for lack of a better expression, we will refer to as 'garden production systems' in describing various types of nonconventional or nonfield agriculture production, particularly in developing countries. Partly as a result of segmentation and/or fragmentation of the production activities, garden production systems have been trivialized, and their research importance and contribution to food security in developing countries severely limited in the scholarly literature. Garden production systems in Ghana (and most of the developing world) are different in many ways from notions of a garden in Western industrialized countries. The scholarly literature has complicated this understanding by attempts to separate and/or define various types of garden operations (see, for example, Niñez[3], Soemarwoto and Conway[6] and Ruthenberg[14]). It is therefore important to clearly understand the production systems that were investigated in this research project.

Earlier definitions describe a garden as a place were horticultural crops are grown, reflecting the Latin derivative of horticulture or *hortus* (which means 'garden'). However, there is no consensus among scientists on the boundary or a clear line that separates field crops from horticultural crops. The garden systems studied in this project had various field, horticulture and root and tuber crops, as well as fruit trees. Garden operations in sub-Saharan Africa and other developing countries have been given various appellations, including home garden, household garden, backyard garden, kitchen garden and market garden[1,3,15,16]. Kroll[16], for example, referred to an aspect of this practice as 'market gardening', which appears to reflect the primary economic purpose of the production activity—for marketing. In contrast, Topoleski[17] referred to a similar production system as 'vegetable gardening', and

appeared to highlight the types of crops managed, as opposed to, say, the end use or economic role of the operation. Furthermore, concepts such as 'household garden'[3] appear to suggest the economic agent who manages and/or uses the produce from the production system, distinct from large-scale market or commercial gardens. Fernandes and Nair[1] acknowledged the existence of different names for this unique agricultural production system, but also refer to 'homegardens' as multipurpose land-use systems, managed 'within the compounds of individual houses'. Yet, many of the garden operators in our study managed their production systems not only for home consumption and sale to various end users, and distributors and retailers, but also managed a combination of various vegetables, legumes, cereals, roots and tubers, herbs and fruit trees. In addition, while some of the gardens were near homes and homesteads, others were located far away from homes and compounds (i.e., in bushes and river valleys). Consequently, we argue that the common definitions in the current literature confuse and/or misrepresent the garden production systems studied.

The terms 'urban and peri-urban agriculture' have also been used to describe some garden production systems or, more accurately, refer collectively to agricultural production (including horticulture, floriculture, animal husbandry, as well as forestry and aquaculture) in both urban and peri-urban settlements[18]. It is, however, important to note that all the production systems in this study were clearly different from a farm, or what Niñez[3] referred to as field agriculture; in terms of size, intensity of management and philosophy. Consequently, for lack of a more appropriate expression, we refer to the agricultural production systems investigated in this study as 'garden production systems'.

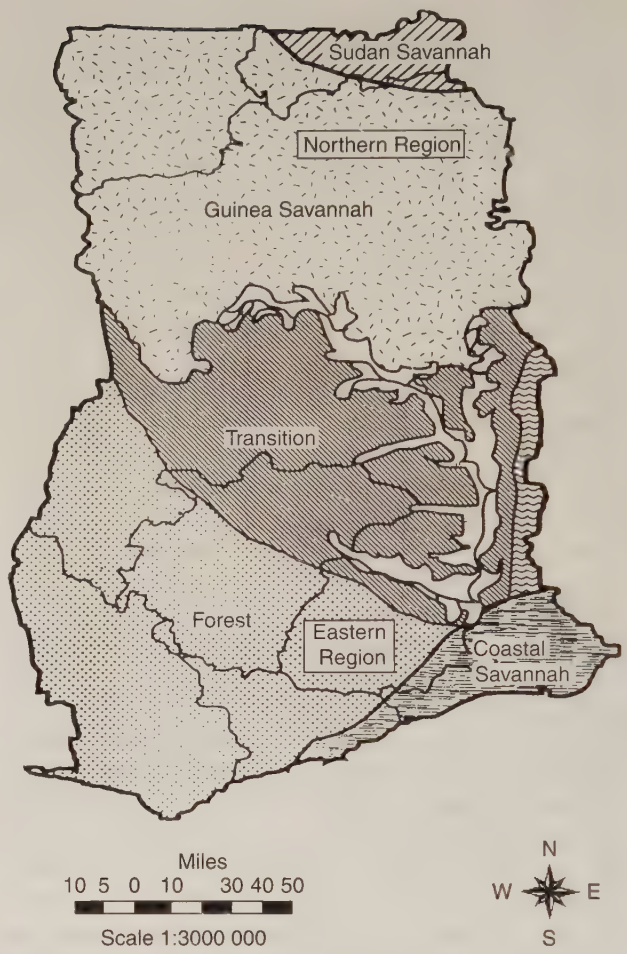

Figure 1. Major agro-ecological zones of Ghana.

Study Method

A rapid rural appraisal (RRA) of garden production systems in Ghana and a formal survey of gardeners were conducted. The RRA helped to clearly identify important geographical areas with significant garden production, as well as the various types of garden cultivation (with a view to capturing as much diversity in garden production as possible). The RRA process involved informal discussion with farmers, extension officers and other key agricultural-sector stakeholders within the areas visited. Random visits were made to farming communities, and towns and villages, during which the multi-disciplinary research team engaged farmers in discussions about their garden production practices, using a prepared checklist of issues. Information generated from the RRA survey helped in the design of specific questionnaires for the formal survey, and in developing the sampling method. Agro-ecological, climatic and cultural factors affect the type of garden operation managed in sub-Saharan Africa[15]. Thus, based on results from the RRA and existing literature, two administrative regions, the Upper East Region and Northern Region were selected to represent, respectively, the Sudan savannah and the Guinea savannah agro-ecological zones of the country (Fig. 1). The Eastern Region was selected to represent the forest agro-ecology in southern Ghana. Two administrative districts were then selected from each of the three regions for more in-depth study, namely: the Bongo and Bolgatanga districts in the Sudan savannah zone of the Upper East Region; West Dagomba and Tolon-Kumbugu districts in the Guinea savannah zone of the Northern Region; and East Akim and New Juaben districts, representing the moist deciduous forest of the Eastern Region (Table 1).

The three agro-ecological zones and their populations of garden producers are not exactly identical in terms of climatic conditions and the specific garden crops and cropping systems managed. However, there is substantial similarity within each agro-ecological zone. For example, inter-cropping maize with cassava, plantain or cocoyam is a common cropping system in the forest region, while cereals such as millet, sorghum and maize are more common in the Guinea savannah. For such populations, stratified sampling generates more accurate results[19], and hence was used in the survey. The three agro-ecologies were the strata, and samples were selected from each stratum. To generate more reliable survey responses from a population with limited formal education, self-administered face-to-face interviews were conducted using a structured questionnaire.

Table 1. Survey sample characteristics, 2000 survey.

	Agro-ecological zone		
	Sudan savannah (Upper East Region)	**Guinea savannah (Northern Region)**	**Moist semi-deciduous forest (Eastern Region)**
Study areas			
Administrative districts	Bongo and Bolgatanga	West Dagomba and Tolon/Kumbugu	East Akim and New Juaben
Mean annual temperature (°C)	30	28	25
Mean annual rainfall (mm)	1000	1100	1200
Gender of operators (number)			
Female	13	11	42
Male	87	89	58
Employment status (% of garden producers)			
Part-time farm operators	17	7	35
Full-time farmers	83	91	65
Education (% of respondents)			
No formal education	64	84	32
Primary (6 years)	26	4	8
Middle (10 years) or Junior Secondary (9 years) school	6	9	44
Senior Secondary School or GCE O Level	0	1	6
Tertiary (post-secondary) education	4	1	9
Farm family size (individuals per household)			
1–5	21	4	34
6–10	38	33	47
11–15	31	23	12
16–20	7	17	4
>20	3	22	2

GCE, General Certificate of Education.

The study areas in the two savannah zones also represent indigenous cultures that are predominantly patrilineal, while the native population in the Eastern Region represents a matrilineal heritage. Soemarwoto and Conway[6] found that women were the primary managers of gardens in Java Island, Indonesia and, consequently, hypothesized that garden production systems are more likely to be developed among matriarchal societies. In addition, inhabitants in the Guinea savannah zone in Ghana include Muslim ethnic populations, whose adult females tend to be less involved in agriculture, and more so in commerce and marketing of general merchandise. Thus, the ecological zone analysis could also capture cultural variability and gender effects.

The formal survey process involved first compiling a comprehensive list of villages and settlements, reflecting urban, peri-urban and rural areas. For each of the three agro-ecological zones, a total of 10 units (i.e., villages and settlements) were randomly selected from the list, using proportional sampling techniques. A comprehensive list of garden producers was compiled from the 10 units, and then 10 garden producers were randomly selected. This generated 100 respondents for each of the three agro-ecological zones, and a total of 300 respondents. A pre-tested questionnaire was then administered to all 300 respondents during August to November 2000.

Characteristics of Survey Respondents

Among the 300 garden producers, 27% were females, while the majority (73%) were male operators (Table 1). By comparison, the national gender distribution of farmers is 38% female and 62% male[20]. Thus, more females tend to be involved in field agriculture than in garden production, primarily because of limited access to suitable land for women gardeners. There was also a substantially higher number of male garden operators in the two savannah zones, compared to the forest agro-ecology. The highest percentage of male garden operators was from the Guinea savannah (89%), followed closely by the Sudan savannah (87%). In contrast, there were slightly more female garden operators in the forest zone of the Eastern Region (58%) than male operators (42%). This finding is significant because it supports the earlier argument about gardening. That is, garden production in many parts of northern Ghana constitutes an important component of a household's food production activity, whereby adult male farmers (who are generally the head of the households in these predominantly patrilineal societies), see themselves, culturally, as the breadwinners for their families.

In such predominantly agricultural communities, land is also a major constraint to farming, particularly in densely

populated areas of the Upper East Region. Consequently, gardening provides the main source of household food. This hypothesis is consistent with the survey results on the proportion of full-time versus part-time operators across the three agro-ecological zones (Table 1).

Although the majority of garden operators in all three agro-ecological zones were also full-time farmers, the forest zone in the Eastern Region had the lowest proportion of full-time farmers (65%), compared to the Guinea savannah (91%) and Sudan savannah (83%) zones. In general, nonfarm employment opportunities in the southern part of the country are better than in northern Ghana, and partly explains why a substantial proportion of the population in the Eastern Region are employed in the nonagricultural sector. In the northern sector of the country, most farmers farm around compound homes and homesteads to supplement food supplies from bush farm fields.

The Northern Region had the highest rate of respondents who had no formal basic education (84%), followed by respondents from the Sudan savannah in the Upper East Region (64%) (Table 1). In contrast, 32% of respondents from the forest agro-ecology had no primary education. The national illiteracy rate (i.e., for 15 years and older) averaged for 1990–1995 was 40%[21]. Farm labor demand in northern Ghana typically results in withdrawal of students from school to help in family farms, especially during peak farming seasons[22]. This observation explains, at least in part, the high illiteracy rate in the region as a whole. In addition, many Moslem families, which is a dominant religious faith group in the Upper East and Northern Regions, often require their children to attend Arabic schools, sometimes as a substitute for the formal (Western) education system. Thus, the high demand for farm labor partly accounts for the lower rate of elementary school enrolment in these regions. It is also significant to note that a small number of garden operators in all the agro-ecological zones studied had post-secondary education, and were operators who supplement their incomes and/or food requirements from gardening. The majority of such well-educated garden operators were from the forest agro-ecology (9%). By comparison, 1% of such garden operators were from the Guinea savannah, and 4% from the Sudan savannah zone.

Across all three agro-ecological regions, the modal household size was between 6 and 10 individuals (Table 1). Within this group, the highest proportion of households (with 6–10 persons) was from the forest zone (47%), while the lowest was from the Northern Region (33%). The highest proportion of small households (with five individuals or less) was for respondents in the forest zone (34%), while the lowest percentage was reported for respondents from the Northern Region (4%). In general, strong extended family ties in many traditional Ghanaian societies result in large households, with family units of close relatives (i.e., husband, wife, married sons and their wives and children or a husband with several wives and children) living as a household. Such a household typically undertakes farming activities together, and may cook and eat together. Family size tends to be higher in households with lower literacy rates[23]. In addition, Moslem families (consistent with their faith and local tradition), are encouraged to support polygamous marriages and, consequently, tend to have bigger households.

Results and Discussion

Characteristics of garden systems

Land acquisition and tenancy arrangements. Traditional communal land tenure arrangements generally dominate Ghana's productive agricultural lands, with slight modifications depending on socio-economic dynamics[24] and cultural considerations. Migration can have significant policy implications in terms of actions for improving tenure arrangements for migrants and city dwellers involved in significant garden production. Consequently, this study investigated the tenancy status of garden operators by asking whether the respondent is a native of the area or a tenant operator. Tenant gardeners include individuals who have migrated to settle in other communities or who were employed in locations away from their original homes, and tend to farm on rented land.

Across all agro-ecological zones studied, the majority of respondents were natives who own their garden lands. Overall, the two savannah zones have a substantially higher proportion of native operators who live on, and cultivate, family land (Table 2). The results for the forest zone in the Eastern Region indicate an equal split between native garden producers and tenant operators, who typically have only usufruct rights to the land. The Eastern Region had a relatively high tenant population (50%), out of which a majority (88%) acquired their own land for cultivation. For example, some respondents used part of their (undeveloped) residential land (acquired through outright purchase) for garden production. An implication of this result is that clearly defining landed property rights and tenancy arrangements is important, and can help minimize land disputes arising not only from real estate development, but also from agricultural uses. For example, tenant operators are vulnerable to accepting vague tenancy agreements in which a landlord's assessment of shared tenancy arrangement is delayed or postponed until crop yield is observed[24]. This can pose problems, because the tenant would have difficulty rejecting the terms of the arrangement since the operator cannot abandon the crops already being cultivated. It was found that operators who owned their garden land put more effort into maintaining and improving the productivity of the plot, consistent with the observation in field agriculture. Although this is no novel finding, it is significant to note that certainty regarding farmland ownership allowed for incorporating perennial food and medicinal plants, and fruit trees, into the production systems. In turn, this has implications for labor use and management, and overall household food self-sufficiency.

Table 2. Garden production system characteristics, according to agro-ecological zone.

	Agro-ecological zone		
	Sudan savannah (Upper East Region)	**Guinea savannah (Northern Region)**	**Moist semi-deciduous forest (Eastern Region)**
	% of respondents		
Tenancy status (%)			
Native	97	99	50
Tenant or settler	3	1	50
Land acquisition/ownership (%)			
Family land	87	96	88
Rented land	2	3	11
Share cropping	0	0	2
Allocated free	4	1	9
Other	7	0	0
Location of gardens (%)			
Around homestead	98	93	98
Near river valley/water source	0	1	1
Away from home	2	6	0
Other	0	0	1

Location of garden fields

Although garden production systems in sub-Saharan Africa are generally located around or near the home, it is also common to locate such production activities close to or adjacent to a reliable source of 'irrigation' water (e.g., river, pond, well) or soil moisture (e.g., river valley). Location of a garden has implications for resource use efficiency, especially household time allocation. For example, in a study on time allocation for farmers in North-East Ghana, Tripp[25] reported that adult males spent slightly more time walking to farms (0.3 hours per day), compared to females (0.2 hours a day). The majority of garden plots were located close to the homestead, across all three agro-ecological zones (Table 2). However, a small proportion were also located away from the homestead, either because of the need for irrigation water during dry season gardening, or because productive land was not available near the homestead. Garden operators who cultivated land that was away from the homestead were from the two savannah regions only. This is consistent with the hypothesis that land that is suitable for garden production and located away from the homestead is more critical in the savannah regions than in the moist forest region[22]. On the other hand, no producers in the Sudan savannah reported siting their gardens near irrigation water sources, away from home. In contrast, 1% of gardeners in both the Guinea savannah and the moist forest zones considered irrigation water source as a primary reason for selecting a location. Location of garden production systems could therefore serve as (indirect) indicators or monitoring systems for particular ecological conditions. Other factors influenced the location of garden plots, and complicate interpretation of the above results. For example, some respondents reported that the crop variety managed (i.e., early versus late maturing variety) was influenced by whether a garden is near the homestead or not. Thus, the food security needs of a household, which change from year to year and even from season to season within a given year, influenced the choice of a variety through location of the garden. Reducing theft of crops (such as yams and plantain) and damage by animals (mainly in the moist forest zone) were also reported as major factors that influenced the location decision.

Production and management practices

Important cultural practices used in managing garden production systems include use of various fencing devices to reduce animal and pest damage, land preparation methods and fertilizer application. Some of these management and cultural practices were different, depending on the agro-ecological zone and type of cropping systems managed.

Fencing. A major constraint to garden production, as reported by survey respondents, was destruction of crops by free-range livestock (e.g., goats, sheep and cattle) and poultry. In general, reported damage by animals tended to be more serious for gardeners in rural areas than in urban/peri-urban locations, as expected, because free-range animal husbandry is more common in rural settlements. One method of preventing animal damage to garden crops is by fencing. The two main fencing methods gardeners used to protect garden crops from livestock and animal pest damage was by fencing using locally available materials such as tree branches, or planting hedges (i.e., living fences). Living hedges that were used include milkbush (*Thevetia peruviana*), Madras thorn (*Pithecelubium dulce*), duranta (*Duranta plumieri*) and thumbergia (*Thumbergia erecta*), with the most common being milkbush and Madras thorn.

Table 3. Garden production and management practices.

Management/cultural practice	Agro-ecological zone		
	Sudan savannah (Upper East Region)	Guinea savannah (Northern Region)	Moist semi-deciduous forest (Eastern Region)
	% of respondents		
Type of protective fencing			
Hedged (live plants)[1]	0	0	10
Fenced (using miscellaneous materials)	26	48	12
No protective fence/hedge	74	52	76
Land preparation			
Ridging/seed beds	3	24	3
Mounds	2	0	1
Tractor	0	48	0
Slash and burn	0	3	9
Hoe	94	11	83
Other method	1	13	3
Fertilizer/manure application			
Compound fertilizer	0	44	5
Sulfate of ammonia	2	16	10
Superphosphate	0	1	5
Organic manure	0	22	10
Urea	2	0	0
Other/not sure of name	0	15	3
None	97	1	68

[1] Common living hedges included milkbush (*Thevetia peruviana*), Madras thorn (*Pithecelubium dulce*), duranta (*Duranta plumieri*) and thumbergia (*Thumbergia erecta*).

The results summarized in Table 3 suggest that the majority of gardeners (67%) do not use any protective fencing, while the remaining respondents established either a hedge (i.e., living fence) or made a fence using locally available miscellaneous materials. Secondly, living fences or hedged gardens were practiced primarily in moist forest gardens, where year-round moisture conditions sustain hedge growth. On the other hand, fenced gardens (using various types of local materials) were reported in all three agro-ecological zones. The highest proportion of fenced home garden fields was observed in the Northern Region (48%), followed by garden operations in the Sudan savannah (26%). By comparison, only 10% of fields were fenced or hedged (using live plants) in the moist forest of the Eastern Region. Fewer gardens were protected from livestock and animal pests in the forest agro-ecology primarily because there are very few livestock farms managed in the area. On the other hand, the grasslands of northern Ghana are more suitable for animal husbandry. A chi-square test on whether there is an association between land tenure status and protective fencing method used by gardeners was not significant ($\chi^2 = 3.285$, $P = 0.4501$). Thus, the type of protective garden fencing used was not influenced by tenancy status (i.e., native versus tenant) of the gardener.

Land preparation. Survey results on land preparation for planting provide important insights on the effect of agro-ecology on crop production practices. Tractor ploughing was the most common method of preparing land for gardeners in the Northern Region (48%), followed by ridging using a hand hoe or bullocks (24%) (Table 3). By comparison, ploughing using a hand hoe was the most common in the Upper East (94%) and Eastern Regions (83%). It was significant to find out that 9% of garden fields in the Eastern Region were prepared by slashing and burning, which is the most common method of preparing farm fields in southern Ghana. Respondents reported that garden fields were prepared using a hand hoe because that method tends to reduce exposure of the soil to drying and, therefore, helps in conserving soil moisture, particularly during the dry season. In addition, tractor ploughing is more difficult during the dry season, when the soils are quite dry.

Fertilizer application. The amount, if any, and type of fertilizer used depended on the type of crops and trees cultivated. In general, there was very limited chemical fertilizer applied in gardens in the Sudan savannah and forest zones (Table 3). The overall low rate of chemical fertilizer use is because of the high cost, after fertilizer subsidies were removed in the 1980s. Removal of fertilizer subsidy largely resulted in fertilizer prices rising faster than producer prices of food products, thereby making fertilizer use less profitable than it was before the subsidy period[26]. In contrast, the majority of gardeners (76%) in the Northern Region applied one form of chemical fertilizer or the other. The relatively high use of chemical fertilizer in the

Northern Region was because two of the leading crops grown in gardens in the area (i.e., maize and rice) require fertilizer or other supplemental nutrients in order to generate reasonable marketable yields. On the other hand, the culture of cowpea, which was the dominant crop grown in gardens in the Upper East Region, does not involve fertilizer. In addition, financial hardships faced by farmers in the Upper East Region as a whole results in farmers and gardeners mining soil nutrients to produce crops. Consequently 97% of respondents in the Sudan savannah did not apply any fertilizer or manure.

By comparison, plantain and cassava dominate the crops planted in the Eastern Region, and these crops culturally are not fertilized. This largely explains why 68% of gardeners in the region did not use any manure or fertilizer. Furthermore, soils in the districts studied in the Eastern Region are inherently more fertile than in the other agro-ecological zones.

Role of gender in garden production systems

Knowledge of the role of gender in garden production has implications not only for national agricultural policy, particularly for technology development and extension delivery, but also for economic/development planning and poverty alleviation. Previous studies for Ghana suggest that most food crops cannot be classified as exclusively men's crops or women's crops, based on the proportion of women and men who manage specific crops[22,27]. Culturally, gender responsibilities within Ghanaian farm households are linked more to specific farm activities than to particular crops. In addition, the literature on gender and field agriculture in Ghana (and Africa as a whole) suggests that adult male labor and female labor are not interchangeable[27]. These two hypotheses have not been tested for garden production systems. It is not clear whether particular garden production and management activities can be classified as exclusively women's activities or men's activities, based on the proportion of women and men who undertake those activities. Therefore, this study investigated roles that adult males and females play in garden production and management, and in the marketing and use of products from gardens, according to agro-ecological zones. As noted earlier, there are important cultural and customary differences among the populations in the areas studied, which could influence gender roles in garden production and other household activities.

The results in Table 4 allow us to draw several conclusions. First, there are few gardening activities that can be classified as exclusively women's activities or men's activities. Secondly, the few patterns observed depended on the agro-ecological region, and were not consistent across all agro-ecological zones. Consequently, for the country as a whole, most garden production activities cannot be classified as tasks exclusively for only one gender. In addition, most garden activities tended to be more gender balanced in the moist semi-deciduous forest than in the two savannah zones (Table 4). This pattern is partly because of the type of crops managed in the garden systems. For example, while many of the crops managed in the forest region (e.g., banana, plantain, cocoyam and maize) tended to be used for household consumption, as well as sold to generate cash income, several crops in the savannah region tend to be cultivated primarily for sale (e.g., tobacco) or for consumption (e.g., sorghum and millet). This finding is consistent with those of Doss[28], who reported a disproportionately adult male involvement in cropping practices for which the adult male manages revenue from the products sold.

Males disproportionately performed only three activities, of which none was in the moist deciduous forest zone. An activity is disproportionately done by a particular gender, say men, if the proportion of 'males only' undertaking that activity is greater than the proportion of gardeners who are females, and the activity was not done by 'both genders'. In the Sudan savannah, threshing of cereal grains was done primarily by males (87% of respondents), although 13% of those involved in threshing cereals were women. In the Guinea savannah, land preparation and transportation of garden produce were the only tasks done almost exclusively by men. The remaining garden production activities studied were undertaken by either gender, depending on household labor allocation priorities.

In general, garden production activities that were not exclusively done by only one gender varied considerably across the three agro-ecological zones. A surprising finding was that a muscularly strenuous activity such as land preparation, which is a traditional male activity in field agricultural systems across many agro-ecological regions[22], had very little male involvement, especially in the Sudan savannah and moist semi-deciduous forest garden systems. In the forest zone, land preparation was done by 44% of males, compared to 12% in the Sudan savannah. In both the Sudan savannah and moist semi-deciduous forest zones, female garden operators owned and managed garden systems for producing food crops that are critical to household food needs. This need prompts them to be more involved in most operations, with little involvement by household men. By comparison, many gardens in the Guinea savannah serve to generate cash income, thereby shifting the gender roles for specific activities. Women in Upper East Ghana were therefore engaged more in use of the hand hoe than their counterparts in the Northern and Eastern Regions. Consistent with the food security objective for women's involvement in garden production, females tended to be involved in vegetable and leguminous crops (especially in the Guinea savannah and moist deciduous forest areas), while male garden operators tended to cultivate cereals and cash crops and fruit trees. Furthermore, women tended to invest more time in garden operations than males in the same household, consistent with the findings of Soemarwoto and Conway[6]. It is therefore important to consider these gender characteristics and variations when developing appropriate technologies and inputs, and extension programs for the various activities discussed above.

Table 4. Gender patterns of garden production and management, by selected activities and agro-ecological zone, 2000 survey.

Agro-ecological zone	Activity	Females only	Males only	Both genders	Not applicable
		% of respondents			
Upper East Region (Sudan savannah)	Land preparation	3	12	84	2
	Planting	29	0	71	0
	Weeding	9	1	90	0
	Spraying	4	22	26	48
	Fertilizer application				
	Harvesting	10	0	88	6
	Carting of produce	16	1	83	0
	Threshing	13	87	0	0
	Winnowing	36	0	64	0
	Storage	68	0	31	2
	Sale of produce	38	0	5	57
Northern Region (Guinea savannah)	Land preparation	1	97	1	0
	Planting	4	21	73	1
	Weeding	6	56	38	0
	Spraying	0	14	6	56
	Fertilizer application	6	56	18	17
	Harvesting	10	21	69	0
	Carting of produce	11	89	0	0
	Threshing	28	6	65	1
	Winnowing	70	14	13	3
	Storage	9	80	9	3
	Sale of produce	20	70	3	7
Eastern Region (forest zone)	Land preparation	16	44	39	1
	Planting	23	28	49	0
	Weeding	22	35	40	3
	Spraying	4	14	1	81
	Fertilizer application	1	4	8	86
	Harvesting	21	29	46	9
	Carting of produce	36	20	34	11
	Threshing	12	5	8	76
	Winnowing	22	35	40	3
	Storage	15	7	6	72
	Sale of produce	12	1	43	44

The roles played by men and women in agricultural activities vary from one agro-ecological zone to another, primarily because of ethnic and customary differences. Such roles are related to the culture (i.e., historical and contemporary) of the people concerned. For example, Table 4 suggests that land preparation (97%), carting of produce (89), storage (80%), sale of produce (70%) and, to a lesser extend, weeding (56%) are carried out mostly by men in the Northern Region. In this region, women are also more involved in threshing and winnowing small grains, and (together with their male partners) in planting, harvesting and threshing.

Comparison of field agriculture and garden production systems

Across all the agro-ecological zones studied, the garden crops and other plant species identified were much diversified, compared with the observation in farm-fields. This observation is consistent with the theory on agro-ecosystem sustainability[29], and case research on garden production[6]. In addition, the total number of different garden plant species managed increased as one progresses from the more arid, higher-altitude Sudan savannah, through the Guinea savannah to the lower-altitude, moist forest region. In a study for Java Island, Indonesia, Soemarwoto and Conway[6] also reported lower biodiversity (and smaller size gardens) as altitude increases. Furthermore, garden production systems tend to generate year-round production of food and cash crops and medicinal plants, while farm-fields (in the same region) tend to be more seasonal in generating outputs. This is not only because more diversified perennial food crops are cultivated in gardens than in farm-fields, but is also due to the observation that small-scale irrigation, typically using watering-cans, made garden production possible, especially during the dry season. In other words, field agricultural production systems are more vulnerable to rainfall variability than garden production.

The majority of farmers managed only one garden field, although a very small proportion cultivated more than one.

The highest proportion of gardeners who managed only one field was from the moist forest of the Eastern Region (97%), followed by respondents from the Guinea savannah in the Northern region (82%), and then the Sudan savannah in the Upper East Region (73%). The remaining operators managed two garden fields. By comparison, Ewusi[24] reported that, in the formal agricultural sector, 25% of Ghanaian farmers operate only one farm-field, while the remaining 75% manage two or more. The number of holdings is substantially lower among garden operators, primarily because many of these gardeners tend to also manage farm-fields. In addition, many gardeners typically have limited access to garden land compared to farmlands in the formal agricultural sector.

Garden production as a whole also has a higher proportion of several economically underexploited fruit trees, compared to fruit trees cultivated in the formal field agriculture sector. These include nontraditional citrus species, e.g., lemon (*Citrus limon*), nontraditional varieties of mango (*Mangifera indica* L.), avocado (*Persea americana* Mill.), guava (*Psidium guajava* L.) and pawpaw (*Carica papaya* L.). In addition, across all three agro-ecological zones, a variety of spices and medicinal herbs with considerable economic potential, but which remain unexploited and underutilized, are managed almost exclusively in garden systems. These include ginger (*Zingiber officinale*), bush okra (*Corchorus olitorius*), a variety of pepper (*Piper nigrum*) and nunum (*Ocimum gratissimum* and *Ocimum viribis*).

Cultivated medicinal plants and herbs were managed almost exclusively in gardens, as opposed to farm-fields. Thus, national programs to promote such nontraditional agricultural production and conservation of genetic resources need to be customized for, and emphasize, garden production systems. In addition, research into the agronomy and farm-management aspects of such economic fruit trees, and herbs and spices needs to be incorporated into national agricultural research and policy initiatives.

Although gardens had more biodiversity and mixed cropping systems, including food crops and cash crops, compared to field agriculture, they also had a considerable variety of perennials, ornamentals, and medicinal and herbal plants that are not managed in typical farm-fields. More affluent households tended to include ornamental plants in gardens near homes, along with food crops, while less affluent households tended to grow food crops and fruit trees (to supplement household food shortfalls) and a few cash crops. It is also significant to note that, in many households in the Sudan savannah, garden production systems were the primary household food source, with no farm-field production.

Varieties planted in gardens versus farm-fields. The study also investigated whether crop varieties planted were similar in both gardens and bush farm-fields. This information is important not only for developing national plant genetic resource conservation and breeding strategies, but also for targeting extension service delivery, agricultural (e.g., seed) technology development and policy decision-making. The majority of respondents in all three agro-ecologies studied planted similar crop varieties in their gardens and bush farms. In the Upper East Region, for example, 86% reported using the same varieties. Similarly, 73% of respondents in the deciduous forest zone reported that they used the same crop varieties regardless of the production system managed.

Farmers who planted different varieties attributed this to problems with theft of produce from bush fields, differences in soil fertility conditions and uncertainty about land tenure arrangements. Some farmers in the Eastern Region, for example, reported that they planted varieties of plantain that mature into heavier bunches from gardens located around homes, while plantain in bush farms had to be harvested early, in order to reduce theft, thereby compromising yield gains.

Contribution of garden production to household food security

A challenge to determining the importance of garden production to household food security is that respondents do not keep records of production. Secondly, most products from gardens are harvested in small amounts when needed and consumed immediately (e.g., one or two tubers of yam or cassava, or a few peppers), or sold to a ready market (e.g., a bunch of plantain, or a few bundles of kontomere, i.e., cocoyam leaves). Thus, we could not rely on respondent estimates of amount of garden production as a criterion for judging the contribution of garden crop production to household food security. Instead, as researchers, we were interested in a very fundamental question, namely: what are the most important food crops cultivated in gardens (as opposed to bush farms)? The second research issue was to determine the proportion of food produce that was consumed in the household, versus the proportion sold to earn cash income.

Although, for the country as a whole, a variety of food crops are cultivated in gardens, each agro-ecological zone emphasized a set of four main crops. However, the actual food crops depended on the agro-ecological zone (Table 5). In the Sudan savannah, gardeners cultivated mainly millet (49%) and sorghum (36%), while the majority of respondents in the Guinea savannah intercrop maize (90%) with either yam or vegetables. By comparison, gardeners in the forest zone plant starchy staples, particularly plantain (85%) and cassava (5%), along with other crops such as cocoyam and pineapple. The results suggest that cereal grains are the garden crops of choice in the savannah regions, while starchy staples (e.g., plantain, cassava, cocoyam, etc.) tend to dominate the choices in the forest region.

Given that there were no production records, one of the appropriate ways of assessing the contribution of gardening to household food needs is to examine the percentage, as opposed to the actual amount[19], of garden food production that is consumed at home versus the proportion that is

Table 5. Importance of garden production, 2000 survey.

	Sudan savannah (Upper East Region)	Guinea savannah (Northern Region)	Moist semi-deciduous forest (Eastern Region)
Primary (i.e., most important) food crops cultivated (%)[1]			
Maize	0	**90**	**2**
Sorghum	**36**	0	0
Millet	**49**	0	0
Cowpea	**9**	0	0
Groundnut	**6**	0	0
Vegetables	0	**4**	0
Yam	0	**4**	1
Plantain	0	**1**	**85**
Cassava	0	0	**5**
Other crops	0	0	**10**
Proportion of garden produce sold (%)			
0 (i.e., all consumed)	86	40	49
10	5	4	0
20	0	6	4
30	0	11	0
40	3	13	2
50	5	1	6
>50	1	25	39

[1] For each agro-ecological zone, figures in bold indicate the dominant or most important garden crops.

marketed. The data were analyzed with agro-ecological zone as the independent variable[19], because we hypothesized that the proportion of garden food consumed will depend on the agro-ecological region of respondents. Thus, respondents were also asked to report the proportion of produce from garden production that was consumed versus the proportion marketed for cash income (Table 5). The results indicate that the majority of gardeners in the Sudan savannah region (86%) manage their operations exclusively to meet household food needs. By comparison, 49% of garden operators in the moist forest zone consumed all the food grown in their gardens, compared to 40% for the Guinea savannah. The result for North-East Ghana is consistent with the observed high population density in the region, with highly fragmented agricultural land holdings and chronic annual food shortages. Consequently, garden operators planted major staples (i.e., millet and sorghum) and vegetables on their garden fields, which tended to be the only agricultural land available to most households. Household food security is therefore a major survival issue in this region. Such garden foods constitute the bulk of the energy intake of many households.

In the Guinea savannah zone, 36% of households sold between 10 and 50% of produce from gardens to generate cash income. There were no households that sold more than half the total garden production. The top three garden crops that were sold by operators in the Guinea savannah were groundnuts (40%), tobacco (40%) and rice (20%). On the other hand, fruit trees were the products sold for cash income in the moist forest region, and included citrus, mango, cocoa and cashew.

Medicinal uses of garden plants. The medicinal uses of selected plants cultivated in gardens, as reported by survey respondents, are summarized in Appendix 1. Thirty-three percent of respondents in the moist forest zone of the Eastern Region reported that, in their gardens, they managed food crops and trees that were also used for medicinal purposes. The medicinal importance of garden plants in the more arid agro-ecological regions was lower (9% of respondents in the Northern region, and 2% for the Upper East Region), compared to the forest region. The single most important medicinal tree in the two savannah regions is the neem tree (*Azadirachta indica*). By comparison, 75% of those who cultivated plants with medicinal properties in Eastern Region identified plantain (*Musa* sp.), along with several herbs and vegetables (25% of respondents). For example, it was reported that the sap from *Musa* sp. is used for treating ringworm, while the leaf is used as a 'band-aid' to cover bruises and cuts sustained while on the farm. The same region had a wider range of trees with medicinal uses, with 'nunum' (*Ocimum gratissimum*) and mango among the most common. The results therefore indicate that produce from home gardens does not only contribute to food security and income, but also to the health needs of households.

Summary and Conclusions

Household food security considerations prompted some producers to select particular food crop varieties that are more appropriate for only garden (as opposed to field agriculture) production. Proximity to irrigation water, early

maturity to meet critical household food shortages, animal pest damage and human theft of crop produce were key factors considered in selecting particular varieties for garden production. Thus, seed technology development needs to target garden production systems, since some crop varieties were cultivated only in gardens.

In general, each agro-ecological zone concentrated on a set of four main crops, unlike the practice in field agriculture in the country, but the actual crop species cultivated depended on the agro-ecological zone. Nearly all cultivated medicinal plants in the study area were managed in gardens, suggesting that policies and programs for preserving genetic resources, and increasing production of such medicinal herbs and trees, should not ignore garden production systems. There was a high use of chemical fertilizer for garden cash crops that required supplemental nutrients in order to generate marketable yields. Fewer females were involved in garden production than in conventional agriculture. In addition, the number of fields managed was lower among garden operators than farmers who cultivated bush farms, primarily because of limited access to suitable garden land, especially for women. In the Sudan savannah zone, garden production has almost replaced field crop production. Population growth and increasing urbanization in Ghana implies a rising demand for increased quantity and, in particular, better-quality fruits and vegetables. Garden operators will likely respond by improving the quality of garden products sold in markets, by selecting varieties with high market value.

To promote garden production in the country, further research is needed, for example, on the ecological and economic compatibility of different garden plants and species. This knowledge could also provide insight into new crop rotations and planting patterns, while taking into consideration nutritional content and market demand for the produce. In addition, it is important to extend post-harvest technology initiatives to garden products as a way of adding value and invigorating the nontraditional agriculture sector.

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Appendix 1. Traditional medicinal uses of selected cultivated garden plants, 2000 survey.

Plant (common or local name)	Scientific name	Reported medicinal uses
Ginger	*Zingiber officinale*	Various preparations help in relieve catarrh, coughs, sore throats and sinisitus. Digestive aid
Guava	*Psidium guajava*	Extract from leaves used to cure various stomach ailments and diarrhea
Neem	*Azadirachta indica*	Infusion used to cure fever. Extract from seed used as an insecticide for stored grain crops, and for controlling pests on cowpea crops
Nunum (basil)	*Ocimum gratissimum*	Cures constipation, especially for children and pregnant mothers. Sap from leaves used as a nasal decongestant. Leaf extract used as antidiarrheal medicine
Pawpaw	*Carica papaya*	Seeds used as a de-wormer in livestock. Cures tumors. Treatment of dysentery
Plantain	*Musa* sp.	Sap from stem used in treating ringworm. Leaves used as first aid (i.e., as 'band-aid') to cover bruises and cuts sustained during farming

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Responsiveness of certain agronomic weed species to arbuscular mycorrhizal fungi

C. Vatovec, N. Jordan*, and S. Huerd

University of Minnesota, 411 Borlaug Hall, 1991 Upper Buford Circle, St Paul, MN 55108, USA.
*Corresponding author: jorda020@tc.umn.edu

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Abstract

Arbuscular mycorrhizal fungi (AMF) are plant root symbionts that provide many benefits to crop production and agro-ecosystem function; therefore, management of AMF is increasingly seen as important to ecological farming. Agronomic weeds that form a symbiotic relationship with AMF can increase diversity and abundance of agronomically beneficial AMF taxa. Also, AMF can strongly affect plant community composition, and may thus provide some degree of biological control for weeds. Therefore, relationships between weeds and AMF have a dual significance in ecological farming, but are relatively unexamined. In glasshouse experiments, seedlings of 14 agronomic weed species were grown in the presence or absence of AMF inocula sampled from each of three types of cropping systems: organic, transitional-organic or high-input/conventional. For each weed species, AMF root colonization rates and growth responses to AMF were assessed. On the basis of observed colonization levels, the species were classified as strong hosts (five species), weak hosts (three) and non-host species (six). Among species, biomass responses to AMF were highly variable. Strong hosts showed more positive responses to AMF than weak hosts, although the range of responses was great. Non-hosts did not suffer consistent negative biomass responses to AMF, although strong biomass reductions were noted for certain species–inoculum combinations. Biomass responses to inocula from different cropping systems varied significantly among weed species in one of two experiments. Results suggest that weed–AMF interactions can affect weed community dynamics. We recommend investigation of these interactions in agro-ecosystems that use management methods likely to intensify weed–AMF interactions, such as conservation tillage and cover cropping.

Key words: weed ecology, agro-ecological restoration, mycorrhizae, mycorrhizal responsiveness, weed biocontrol

Introduction

The limited biological diversity characteristic of current high-input 'industrialized' farms is an important cause of many problematic aspects of these agro-ecosystems[1], such as high losses of nutrients and soil, and dependence on pesticide and fertility inputs[2]. Consequently, restoration of biodiversity is an important strategy for mitigating these problems[3]. The plant component of agro-ecosystem biodiversity includes crops and weeds. Current evidence[4] suggests that weed species can provide certain agro-ecological benefits and therefore could be a useful biodiversity component, if beneficial weed species can be identified and managed at tolerable levels of abundance. Most ecological benefits from weeds result from interactions between weeds and organisms at other trophic levels[4]. Relations between weeds and arbuscular mycorrhizal fungi (AMF) are an important class of such interactions[4], because of the agro-ecological importance of AMF.

AMF symbiosis has a variety of effects on crop plant biology and functional ecology, including increased uptake of soil nutrients, protection from drought and other environmental stressors, and protection from soil pathogens[5]. Moreover, AMF evidently can positively affect certain important agro-ecosystem functions. For example, diversity and abundance of AMF is increasingly understood to be an important influence on soil quality and tilth[6].

Interactions between AMF and weeds, in particular, could be agro-ecologically significant for the following reasons. First, weeds may serve to maintain diversity and abundance of agronomically beneficial AMF taxa. Several studies have demonstrated that removal of host weeds from agro-ecosystems causes changes in diversity, abundance and functioning of AMF, reducing beneficial AMF effects

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on crop growth[7,8]. Secondly, population dynamics of weed species that host AMF may be affected by interactions with AMF, since these fungi have been shown to affect plant community composition and dynamics[9–13]. In particular, interactions with AMF might serve to increase or maintain populations of weeds that provide some agro-ecological benefit[4], and/or to decrease populations of weeds that are problematic.

In limited studies of relations between AMF and host weed species, AMF symbiosis has been shown to increase growth, seed production and seed quality[14–19]. However, these findings are based on detailed studies of only six agronomic weed species; thus, relations with AMF have scarcely been assessed among agronomic weeds. In particular, little is known of interspecific variation in AMF effects among co-occurring weeds. The magnitude of this variation is important because theory indicates that it strongly influences the potential for AMF to affect weed community composition[20]. In the only comparative study that we are aware of, substantial differences in biomass response to AMF infection were noted in a comparison of two host species, velvetleaf (*Abutilon theophrasti* L.) and yellow foxtail (*Setaria lutescens* L.)[21,22]. In studies of other plant communities[23–26], a large range of plant responses to AMF infection has been observed consistently, suggesting that a similar range may occur among agronomic weeds.

In addition to AMF effects on mutually beneficial interactions with desirable weed species, there is another weed–AMF interaction of potential agronomic significance. AMF can exert strong antagonistic effects on certain non-host plant species, some of which are important agronomic weeds[10,27–32]. Note that these effects are direct, rather than occurring through advantages conferred by AMF to host species growing in mixture with non-hosts. For example, relative growth rate and survivorship of lambsquarters (*Chenopodium album*) was reduced by 42% and 33%, respectively, when grown with AMF[10]. Similarly, in a pilot experiment with six non-host species, we found a consistent pattern of growth inhibition when seedlings of single weed species were exposed to a diverse AMF assemblage. Some of these inhibitory effects were very strong, e.g., a 90% reduction in biomass production by pigweed (*Amaranthus retroflexus* L.), and an 80% reduction in lambsquarters[33]. The mechanistic basis of these antagonistic effects on non-hosts is not clear, although it may result from inhibitory effects of AMF on root development[10]. Many problematic agricultural weeds belong to families that are typically non-hosts[10,34]. Therefore, these observations of antagonistic effects of AMF on non-host species raise the possibility that AMF could provide a broad-spectrum biocontrol measure against non-host weed species.

In the present study, we determined colonization rates and biomass responses to AMF among 14 weed species of agronomic importance, to assess interspecific variation in colonization and growth responses to AMF infection, and AMF antagonism to non-host species. The weed species used in this study were chosen after farmers belonging to a Minnesota (USA) sustainable-agriculture organization were surveyed to identify weeds they found highly problematic. Based on observed patterns of hosting among plant families, we anticipated that eight of these species were potential AMF hosts. To increase the range of inferences regarding weed responses to AMF, we examined weed responses to AMF collected from three different farm management systems: organic, transitioning to organic, and high-input/industrial (hereafter, 'conventional') farms, and repeated our experiment over time.

Materials and Methods

Experimental design

Two similar glasshouse experiments were conducted. The first (Experiment 1) was conducted from May to July 2001; the second (Experiment 2) occurred from November 2001 to January 2002 and used different sources for one inoculum treatment (Table 1). These experiments took place in a single glasshouse, with growth conditions of 27:23°C day:night (Experiment 1) and 20:19°C (Experiment 2). In Experiment 2, natural sunlight was supplemented with artificial light (400 watt high-pressure sodium lamps, 14–16 h day^{-1}). The light intensity at the bench surface was ~1050 µmol photon m^{-2} s^{-1} in Experiment 1, and 600 µmol photon m^{-2} s^{-1} in Experiment 2. The experimental design was a randomized complete block with three factors and 13 replicates. Factors were: (1) three sources of soil inocula (organic, transitional, conventional); (2) presence or absence of AMF (+AMF, −AMF); and (3) 14 weed species (Table 2), seeds from Valley Seed Service (Fresno, California, USA).

Soil media and inocula

A Waukegan silt loam was collected from the Rosemount Experiment Station (Minnesota), sieved to remove large roots and stones, mixed 1:1 with sand, and pasteurized (2 h at 77°C, repeated after 48 h) for use as a 'base soil' mixture. Soil tests were conducted prior to planting and at weed harvest on samples taken from each of the base soil/treatment mixtures. No deficiencies or toxic nutrient levels due to pasteurization were observed (Table 3). Inoculum soils were collected from central Minnesota farms in each of three categories (organic, transitioning-to-organic, or conventional field management) in August 2000 for Experiment 1, and in July 2001 for Experiment 2. Inocula were put in cold storage to preserve AMF diversity and abundance. Infection levels in these experiments were similar to levels observed in earlier studies using freshly collected inocula, suggesting that inocula retained viability during storage. Soils were dried, sieved and mixed within each category to create inocula. We sampled from four organic (Org) farms; each used long rotations of 5–6 crops and cover crops at various points in the rotations, and tillage for weed management (Table 1). Three transitional farms (Trans) were sampled; each used three-crop rotations

Table 1. Cropping system history and weed presence for inocula source fields.

Experiment	Category	History	Weeds present at sampling time
1,2	Organic	Soy, grain, pasture, corn, small grain, alfalfa, corn	Lambsquarters (*Chenopodium album*), pigweed (*Amaranthus retroflexus*)
1,2	Organic	Alfalfa, alfalfa, corn, grain, soy or forage, grain/fall alfalfa, alfalfa, corn	Velvetleaf (*Abutilon theophrasti*), pigweed (*A. retroflexus*), giant ragweed (*Ambrosia trifida*), lambsquarters (*C. album*), foxtail (*Setaria* spp.)
1,2	Organic	Corn, barley, clover, soybean, corn	Dandelion (*Taraxacum officinale*), orchard grass (*Dactylis glomerata*), sweet clover (*Melilotus officinalis*)
1,2	Organic	Soy, small grain (oats)/underseed legume (alfalfa), alfalfa, corn	Foxtail (*Setaria* spp.)
1	Transitional	Wheat/peas, corn, soy-cultivated, corn	–
1	Transitional	Soy, alfalfa transition, corn	–
1	Transitional	Soy, corn, soy, corn	–
1	Transitional	Soy, wheat, soy, corn	Foxtail (*Setaria* spp.)
2	Transitional	Corn, fallow, vetch/rye mix, corn	Milkweed (*Asclepias* spp.)
2	Transitional	Soy, corn, fall rye, pumpkins	Pigweed (*A. retroflexus*), rye volunteer (*Secale cereale* L.)
2	Transitional	Corn, soy, rye, hay, corn	Green foxtail (*Setaria viridis*), lambsquarters (*C. album*), ragweed (*A. artemisifolia*), pigweed (*A. retroflexus*), sowthistle (*Sonchus arvensis*), orchard grass (*Dactylis glomerata*), wild buckwheat (*Polygonum convolvulus*), hairy vetch (*Vicia villosa*), Canada thistle (*C. arvense*), mustard (*B. kaber*), Shepherd's purse (*Capsella bursa-pastoris*)
1,2	Conventional	Corn, corn, soy, corn	None
1,2	Conventional	Corn, soy, corn	None
1,2	Conventional	Corn, soy, corn	Shepherd's purse (*Capsella bursa-pastoris*), lambsquarters (*C. album*), pigweed (*A. retroflexus*), purslane (*P. oleraceae*), milkweed (*Asclepias* spp.), Canada thistle (*C. arvense*)

and tillage for weed management. Four conventional farms (Conv) were sampled; each used corn–soybean rotations and herbicidal weed management; with one exception (Table 1), all inocula were collected from corn fields.

To create sterile inocula lacking AMF and other soil biota, half of each inoculum was pasteurized (30 min at 77°C, repeated once after 24 h) for control treatments (denoted Org−, Trans−, Conv−; live inocula denoted

Table 2. Mean percent root colonization of agricultural weed species to three inoculum types (organic, Org+; transitional, Trans+; conventional, Conv+) and standard error of the mean.

				Root colonization[1]		
Category	**Species**	**Common name**	**Family**	**Org+**	**Trans+**	**Conv+**
Strong host	*Abutilon theophrasti*	Velvetleaf	*Malvaceae*	15 (4.2)	24 (5.8)	32 (5.5)
	Ambrosia artemisifolia	Ragweed	*Asteraceae*	51 (5.0)	52 (3.5)	51 (5.4)
	Cirsium arvense	Canada thistle	*Asteraceae*	32* (8.8)	55 (8.1)	60* (7.5)
	Solanum nigrum	Nightshade	*Solanaceae*	37 (4.4)	36 (9.7)	26 (7.2)
	Xanthium strumarium	Cocklebur	*Asteraceae*	33 (4.3)	37 (3.4)	43 (4.6)
Weak host	*Agropyron repens*	Quackgrass	*Poaceae*	16 (6.2)	8 (3.5)	4 (1.2)
	Setaria faberi	Giant foxtail	*Poaceae*	3 (1.7)	2 (1.6)	0.3 (0.3)
	Setaria lutescens	Yellow foxtail	*Poaceae*	15 (5.3)	14 (4.9)	4 (1.5)
Non-host	*Amaranthus retroflexus*	Pigweed	*Amaranthaceae*	nd	nd	nd
	Brassica kaber	Mustard	*Brassicaceae*	1.3 (0.5)	0.9 (0.3)	0.7 (0.2)
	Chenopodium album	Lambsquarters	*Chenopodiaceae*	0.8 (0.3)	0* (0)	1.4* (0.4)
	Polygonum lapathifolium	Smartweed	*Polygonaceae*	0 (0)	0 (0)	0 (0)
	Portulaca oleracea	Purslane	*Portulacaceae*	nd	nd	nd
	Rumex crispus	Curly dock	*Polygonaceae*	0.9 (0.0)	0.2 (0.2)	2.3 (1.3)

[1] Mean root colonization (%) and standard error (in parentheses) = root length colonized by AMF in Experiments 1 and 2 combined (data were not significantly different between the two experiments).

* Root colonization levels significantly different between inoculum types as determined by ANOVA ($P < 0.05$).

Table 3. Soil chemistry data of greenhouse soils (base soil/inocula mixtures) sampled at time of weed seed planting (a) and weed harvest (b)[1].

Soil		Bray-P[a]	Bray-P[b]	pH[a]	pH[b]	EC 1:1[a]	EC 1:1[b]	OM%[a]	OM%[b]	NO_3[a]	NO_3[b]	NH_4[a]	NH_4[b]	P[a]	P[b]	K[a]	K[b]
		ppm				Mhos $cm^{-1} \times 10^{-5}$		Loss on ignition		ppm in solution		ppm in solution		Total P units		Total K units	
Experiment 1	Org+	24	27	7.7	7.8	27	22	1.5	1.4	5.0	< 5	1.3	0.9	0.516	0.521	< 0.707	2.613
	Org−	20	22	7.8	7.7	24	23	1.2	1.1	< 5	< 5	1.3	1.4	0.551	0.291	< 0.707	1.402
	Trans+	21	27	7.9	7.7	52	54	1.4	1.4	< 5	5.0	1.4	1.0	0.792	0.530	< 0.707	2.369
	Trans−	23	19	8.0	8.0	40	28	0.9	1.2	5.0	< 5	1.6	1.0	0.683	0.619	< 0.707	2.116
	Conv+	32	28	7.9	8.1	28	24	1.3	1.1	7.0	< 5	1.3	1.0	0.948	0.784	< 0.707	2.267
	Conv−	31	28	7.8	8.0	38	28	1.7	1.3	7.0	< 5	1.6	1.0	0.748	0.733	< 0.707	2.033
Experiment 2	Org+	12	11	7.6	7.8	18	21	1.06	1.1	5.0	< 5	0.9	< 0.5	0.204	0.313	1.798	1.949
	Org−	15	16	7.6	7.6	20	21	1.41	1.6	< 5	< 5	1.2	< 0.5	0.260	0.448	2.729	2.835
	Trans+	38	27	6.8	7.4	8	15	0.81	1.2	< 5	< 5	1.2	< 0.5	0.416	0.379	2.788	2.034
	Trans−	37	25	6.9	7.4	8	19	0.67	1.2	< 5	< 5	1.4	< 0.5	0.378	0.523	2.391	2.781
	Conv+	28	19	6.6	7.4	24	15	1.02	1.2	14.9	< 5	1.4	< 0.5	0.474	0.237	3.812	1.622
	Conv−	25	17	6.7	7.4	13	17	0.95	1.2	5.9	< 5	1.6	< 0.5	0.273	0.271	3.108	1.573

[1] Specific soil test information can be found at http://soiltest.coafes.umn.edu/ (accessed 5 February 2005).

Org+, Trans+, Conv+). Inoculum soils for the second experiment were collected from the same farm sites, except for transitional farms as these had become fully organic at the time of the second soil collection. Inoculum soils were generally similar across farm types in a variety of parameters (Table 3). The AMF taxa present in experimental inocula were not identified. A 'microbial wash'[35] was prepared from each inoculum type through an 11 µm sieve and applied to all pots (10 ml/pot), specific to inoculum type, to equalize soil–microbial components between pots containing live-soil and control inocula, such that the main difference between the pots of each soil was AMF. We note, however, that the microbial-wash treatment does not fully equalize non-AMF soil biota between live- and killed-soil inocula; in particular pathogenic fungi whose spores are too large to be present in the wash treatment may be present in live inocula but not in controls. Therefore, weed responses to live inocula should be interpreted with some caution, as they may reflect effects of pathogens in addition to AMF. However, roots of all weed plants were examined for visually apparent disease symptoms after harvest. No symptoms were evident, suggesting that substantial pathogen effects did not occur in these experiments.

Plant growth conditions

Pots (7 cm × 30 cm) were filled with a mixture of base and inoculum soils (550 ml : 80 ml; 13% inoculum), and topped with base soil (80 g) to reduce contamination by water splashing and by air movement in the greenhouse. In agroecosystems, particularly where frequently-recommended measures such as conservation tillage and cover crops are used, weed seedlings are likely to interact with AMF mycelia associated with existing plant roots. To model this situation, we developed an AMF mycelium in the soil prior to weed seeding. After pots were filled with experimental soil mixes, an AMF host species, red clover (*Trifolium pratense*, inoculated with a commercial rhizobium strain, 'Nitragin', LiphaTech, Inc. Milwaukee, Wisconsin), was planted and thinned to 5 plants per pot 7–10 days after planting (DAP) and allowed to grow for 42 days to develop an AMF mycelium in pots containing live inoculum. Clover shoots were harvested after 6 weeks by cutting plants at the soil surface or just under the surface; roots were undisturbed. Weed seeds were then planted and thinned at 7–14 DAP to one seedling per pot. After 42 DAP all plants were harvested. Roots were washed to remove soil and clover roots. Clover roots were easily distinguishable and separated from weed roots. All harvested material (plant shoots and roots) was dried at 70°C for 3–5 days, and total dry biomass was determined. Effects of AMF on biomass production were estimated by calculating mycorrhizal response[25] values, defined as the difference between inoculated and uninoculated biomass means, expressed as a percentage of the inoculated biomass mean.

Table 4. Mycorrhizal responsiveness of agricultural weed species to three inoculum types (organic, Org; transitional, Trans; conventional, Conv) in Experiments 1 and 2.

			Mycorrhizal responsiveness					
			Experiment 1[1]			Experiment 2[1]		
Category	Species	Common name	Org	Trans	Conv	Org	Trans	Conv
Strong host	*Abutilon theophrasti*	Velvetleaf	9	4	20	−179*	29	55
	Ambrosia artemisifolia	Ragweed	45**	54**	49**	14	26	25*
	Cirsium arvense	Canada thistle	51	68*	67	20	42	27
	Solanum nigrum	Nightshade	4	12	−1	−14	−28	−15
	Xanthium strumarium	Cocklebur	nd	nd	nd	38	−74	18
Weak host	*Agropyron repens*	Quackgrass	−51	−24	−106	−2	−6	−21
	Setaria faberi	Giant foxtail	24	22	16	−23	−32	−45
	Setaria lutescens	Yellow foxtail	−15	31	−10	59*	−54*	−87
Non-host	*Amaranthus retroflexus*	Pigweed	17	42	−24	nd	nd	nd
	Brassica kaber	Mustard	6	23	16	−1	12	−76**
	Chenopodium album	Lambsquarters	13	26	32	68	63	−116
	Polygonum lapathifolium	Smartweed	31	−57	9	28	42	44
	Portulaca toleracea	Purslane	21	−11	−3	−83	58	−51
	Rumex crispus	Curly dock	−85*	12	−24	−44	−19	−42

[1] Mycorrhizal response (%) = [(biomass in AMF presence (g) − biomass in AMF absence)/biomass in AMF presence] × 100.
Total biomass of inoculated plant significantly different from non-inoculated control as determined by ANOVA (* $P < 0.05$; ** $P < 0.005$).
nd signifies no data available.

AMF colonization assays

To verify effectiveness of live inocula and absence of contamination in killed-inoculum treatments, colonization rates were assessed in velvetleaf (*A. theophrasti*), a weed species that typically forms abundant mycorrhizae[22] (Table 2). A sample of roots from velvetleaf plants grown in all soil treatments were stained using aniline blue[36] and colonization rates were determined by counting the number of arbuscules, vesicles and hyphae present in each root segment under 200× magnification using the magnified intersection method[37]. To confirm host/non-host status and estimate AMF colonization rates for each host species, similar counts were taken on roots sampled from five plants of each weed species, grown in the inoculated treatments of both experiments (Table 2).

Statistical analyses

ANOVA was used to test treatment main effects and interactions. Separate analyses were carried out for host and non-host species, and for Experiments 1 and 2. An indication of the significance of individual weed species responsiveness to AMF inoculation in each experiment (Table 4) was obtained by doing a *t*-test of biomass differences between AMF+ and AMF- treatments for each weed species in each inoculum[27]. All analyses were done using SAS[38].

Results

AMF colonization

No AMF contamination of control pots was observed in either experiment. Root colonization rates (Table 2) were not significantly different between experiments for any species, though they did vary sharply among species. Based on observed colonization rates, host weed species were found to comprise two groups. Five species were relatively strong hosts, each with mean colonization rates ≥29%. These species were velvetleaf (*A. theophrasti*), ragweed (*Ambrosia artemisifolia*), Canada thistle (*Cirsium arvense*), nightshade (*Solanum nigrum*), and cocklebur (*Xanthium strumarium*). The three other host species, giant foxtail (*Setaria faberi*), yellow foxtail (*S. lutescens*) and quackgrass (*Agropyron repens*) showed colonization rates <16%, and were therefore categorized as 'weak' hosts. Other weed species were regarded as non-hosts. These were pigweed (*A. retroflexus*), mustard (*Brassica kaber*), lambsquarters (*C. album*), smartweed (*Polygonum lapathifolium*), purslane (*Portulaca oleracea*), and curly dock (*Rumex crispus*). Though mustard, lambsquarters and curly dock all were found to have low levels of root colonization of typical morphology (between 0.2 and 2.3%), these species were classified as non-hosts in analyses of growth responses because they have previously been reported only as non-mycotrophic[7,10,25,39]. Likewise, pigweed and purslane were classified as non-hosts, though there was

insufficient root biomass to calculate colonization rates for these species. Generally, colonization levels were fairly consistent across inocula from different cropping systems (Table 1), with the exceptions of Canada thistle (*C. arvense*) and lambsquarters (*C. album*).

Host weed growth responses to AMF inoculation

In Experiment 1, mycorrhizal response values of host species, [(biomass in AMF presence (g) − biomass in AMF absence)/biomass in AMF presence] × 100 (Table 4), indicated large and strongly significant (Table 5) differences in seedling growth responses to mycorrhizal colonization. In this experiment, strong-host species generally benefited more strongly from AMF colonization (mycorrhizal response values ranged from −1 to 68%; Table 4) than did weak-host species (mycorrhizal responses ranged from −106% to 31%), although a large range of values occurred within each host type (Table 4). Only the strong-host species ragweed (*A. artemisifolia*) and Canada thistle (*C. arvense*) showed unequivocally positive responses to AMF colonization, indicating that colonization was beneficial to seedling growth. Mycorrhizal responses of all other host species were not significantly different from zero, and negative estimates were common, especially among weak-host species. Therefore, most host species showed little sign of mycorrhizal dependency (i.e., dependence on AMF symbiosis for growth) under these experimental conditions, despite abundant colonization in certain cases (Table 2).

Weed seedling growth was somewhat reduced in Experiment 2, in which temperatures and light levels were lower (see methods) than in Experiment 1; mean seedling biomass was 0.28 and 0.18 g in Experiments 1 and 2, respectively. In the conditions of Experiment 2, there were no statistically significant differences in mycorrhizal responsiveness among host weed species (Table 5). However, in contrast to Experiment 1, there was significant heterogeneity among weed species in their responses to inoculation from different sources (Table 5). This interaction arose because certain host species, including velvetleaf (*A. theophrasti*), yellow foxtail (*S. lutescens*), and cocklebur (*X. strumarium*), varied sharply in responsiveness across inoculum sources. For example, responsiveness of velvetleaf ranged from −179% in organic inoculum to 55% in conventional soil (Table 4).

Table 5. ANOVA of biomass response to weed species, inoculation (AMF factor) and inoculum source (soil factor), for weed species grouped into host and non-host categories; non-significant effects denoted ns.

Category	Source of variation	Experiment 1 df	Experiment 1 *F*	Experiment 1 *P*	Experiment 2 df	Experiment 2 *F*	Experiment 2 *P*
Host	AMF	1	16.2	0.0001	1	0.1	ns
	Species	6	43.7	0.0001	7	52.0	0.0001
	Soil	2	18.7	ns	2	1.2	ns
	AMF × Species	6	3.4	0.0027	7	1.0	ns
	AMF × Soil	2	0.5	ns	2	2.4	0.10
	Species × Soil	12	2.1	0.02	14	0.9	ns
	Species × Soil × AMF	12	0.4	ns	14	2.7	0.001
Non-host	AMF	1	2.71	0.103	1	0.4	ns
	Species	5	24.8	0.0001	4	38.4	0.0001
	Soil	2	4.8	0.012	2	1.3	ns
	AMF × Species	5	1.2	ns	4	1.5	ns
	AMF × Soil	2	0.5	ns	2	2.3	0.11
	Species × Soil	10	0.6	ns	8	0.6	ns
	Species × Soil × AMF	10	1.3	ns	8	0.8	ns

Non-host responses to AMF presence

Overall, non-host biomass production was not significantly affected by AMF (Table 5). In particular, there was no indication of strong, consistent negative AMF responses by the non-host weed species in either experiment (Table 4), although in a few instances strong and significant negative mycorrhizal responses were observed, e.g., an 85% reduction of curly dock (*R. crispus*) biomass in the organic inoculum of Experiment 1, and 76% reduction of mustard (*B. kaber*) in conventional inoculum of Experiment 2. These negative responses fall below the range of non-significant negative responses that was observed in a number of host species (Table 4).

Discussion

We found substantial variation in mycorrhizal responsiveness and hosting behavior among 14 weeds of temperate field-crop agro-ecosystems. This finding parallels results of previous studies in other ecosystems. Among a group of hosts from a prairie plant community, mycorrhizal responsiveness ranged from 24.5% to 99.4% among warm-season grasses, and ranged from −4.9% to −33.3% among cool-season grasses[25]. Similarly, host species from early-successional temperate grasslands[24,40–42] varied widely in responsiveness. Given the wide range of biomass responses observed among these weed species, it is possible that AMF could have a substantial effect on the dynamics of weed communities containing these species, particularly in agro-ecosystems that minimize soil disturbance and mechanical weed control for soil and water conservation purposes. In such agro-ecosystems, AMF are likely to be more diverse and abundant, and other effects on weed community dynamics (e.g., those of selective tillage) are likely to be less.

We also found that mycorrhizal responsiveness was generally less positive under the reduced light and temperature levels of Experiment 2, a result consistent with the hypothesis that AMF may typically provide lower net benefits to hosts when photosynthesis is restricted[29]. Therefore, our results suggest that weeds under a crop canopy might respond differently to AMF than weeds that

are above that canopy. AMF interactions with sub-canopy weed plants may be a very important facet of weed–AMF interactions, since small, sub-canopy weed plants can produce considerable numbers of seeds[43] and are probably important to the persistence of populations of many weed species. An adequate assessment of AMF effects on weeds requires characterization of variation in AMF–weed relations across relevant ranges of environmental factors. Differences among cropping systems in management or other factors have been shown to cause functional differences in relations between AMF and crop plants[44]. However, we observed little evidence that AMF from different cropping systems had differential effects on weed growth or colonization, although large differences were observed in biomass responses to different inocula in a few cases.

Our finding of considerable variation among common agronomic weed species in colonization and biomass response to AMF raises questions about the effect of weed communities on AMF diversity and abundance. Although critical data on this point are lacking, the higher levels of AMF root colonization observed in strong host species may be associated with higher levels of AMF biomass and spore production by some or all colonizing AMF species in strong hosts, relative to biomass and spore production of these species when colonizing weaker host species. If so, then a weed community composed predominantly of strong hosts would be expected to cause different AMF community dynamics than a weed community of weak hosts. Given that several studies have shown that experimental alteration of weed communities can reduce beneficial AMF effects on crop growth[7,45], attention should focus on identifying weed species that can play an important role in maintaining the beneficial effects of AMF on crop growth and other desirable agro-ecosystem attributes, such as good soil tilth.

We did not observe consistent antagonistic effects of AMF on non-host weed species. Some strong antagonistic effects were observed, but there was no indication of any broad-spectrum biocontrol effect. These findings contrast distinctly with results from our preliminary experiment[33], in which we observed moderate to very large biomass reductions in response to AMF among the same group of non-host species examined in the present experiment. Similarly, a group of eight non-host species (mostly ruderal weeds) showed consistent negative biomass and survivorship responses to AMF[10]. Given the potential value for weed biocontrol of AMF non-host antagonism, it is important to consider reasons for the discrepancy between our results and previous observations of strong antagonistic effects. If non-host antagonism occurs via damaging effects of AMF on seedling roots, as proposed by Francis and Read[10], then it is plausible that non-host weed seedlings may be vulnerable to AMF antagonism only during a certain early phase of development. Our preliminary experiment was carried out in greenhouse conditions similar to those of Experiment 2, and seedling growth rates were clearly slower than in Experiment 1 or 2. Relative to our experiment, the protocol used by Francis and Read[10] may have achieved a higher density or physiological activity of AMF mycelia, by using a mesh screen to create a root-free soil zone containing mycelia supported by living plants. Similarly, seedling growth rates in our current experiment were greater than those in our preliminary experiment. Thus, in previous experiments showing strong antagonism, weed seedlings could have been exposed to stronger AMF effects, or exposed for a longer period, than was the case in our present experiments, and these differences may explain the lack of consistent antagonistic effects in these latter experiments.

We particularly encourage further investigations of weed–AMF communities in agro-ecosystems that make use of conservation tillage and cover cropping techniques. Weed–soil microbiota interactions are likely to be generally stronger in such situations; e.g., weed-suppressive bacterial activity was increased by reductions in tillage intensity[46]. Such management approaches are likely to intensify weed–AMF interactions, including possible weed biocontrol effects, and increases in abundance of beneficial weeds and AMF taxa.

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Book Review

Late Victorian Holocausts: El Niño Famines and the Making of the Third World. By Mike Davis. 2001. Verso, London and New York. US$27, ISBN 1–85984–739–0, cloth.

The history of colonialism and imperialism of the 19th and 20th centuries, and their implications for the present, have generated heated discussion over the years. There are those that stress positive aspects, pointing to the creation of infrastructure such as ports and railroads, the development of a modern bureaucracy that could govern in a post-colonial world, and the introduction of new crops. Others have stressed harmful aspects that colonialism and imperialism had in the colonies and former colonies. Destruction of local industries (such as weaving in India) to help create markets for the products of the industrial revolution in Europe was common. Additionally, colonial and imperialist rulers commonly use 'divide and rule' tactics, creating or intensifying divisions along ethnic or religious lines by setting up one group (frequently a minority) as native rulers working under colonial jurisdiction. Mike Davis has written an ambitious book that stresses the disastrous effects that a combination of weather patterns and social and economic changes brought about by colonialism and imperialism had on hunger and famine through large swaths of globe. The book covers a vast amount of information across a number of disciplines. It attempts to synthesize and explain important historical occurrences and patterns, of continuing relevance to the modern world. How could the effects of these famines have been so severe and what lessons can we learn from those terrible events? The book is divided into four parts: (I) The Great Drought, 1876–1878; (II) El Niño and the New Imperialism, 1888–1902; (III) Deciphering ENSO [the El Niño–Southern Oscillation]; and (IV) The Political Economy of Famine. The first two parts deal extensively with drought-induced famines, made considerably worse because of the effects of colonialism and imperialism. The third part deals with the history and science behind the weather patterns that periodically brought drought to much of the Monsoon area of Asia, as well as other parts of the globe. The fourth part deals mainly with responses of the societies of India, China and Brazil to the combination of colonial heritage and weather patterns.

Capitalism evolved its defining characteristics during the 19th century. It developed as a world system, with a group of wealthy countries at the center and a larger group of countries—either 'deindustrialized' or hindered in their development—in the periphery. As Davis points out in *Late Victorian Holocausts*, 'the looms of India and China were defeated not so much by market competition as they were forcibly dismantled by war, invasion, opium and a Lancashire-imposed system of one-way tariffs. (Already by 1850, imposed Indian opium imports had siphoned 11 percent of China's money supply and 13 percent of its silver stock out of the country.)' During this period, differences in wealth and living standards among countries emerged and then solidified. At the beginning of the 19th century, the general standard of living in what would become the industrialized core capitalist countries was not very different than that in India and China. By mid-century the tide had begun to change, and by 1900 a huge disparity had occurred—with household income in England approximately 21 times that in India. This was caused not only by an increase in income in England, but also a stagnation or actual decline of income in the what is now called the Third World.

Towards the end of the 19th century the pace of colonial takeovers and commercial penetration of poor countries quickened. It was at this time that a number of horrific famines occurred in widely dispersed locations around the globe—as far apart as India, China (especially the loess plateau of the Yellow River in the north-central part of the country) and the northeast of Brazil. Davis's book is devoted to the details of the climatic events that led to the famines, their human costs, why the famines were especially severe, the popular movements that developed in response to pauperization and the changes that occurred in the aftermath. Davis sees the immediate direct consequences of the climatic extremes, the deaths of millions of people, as especially severe because the ways in which villages and countries had traditionally protected their people from such natural disasters had been destroyed by colonialism and imperialism. The staggering devastation caused by the famines, in turn, left countries more susceptible to imperialist penetration. This process solidified the center-periphery order of exploitation that still exits in the early 21st century. Ecologists describe strong ecosystems as *resistant* to catastrophic events, such as torrential rains, and *resilient*—able to bounce back quickly when such events occur. Although not using this terminology, what Davis describes is the weakening of the social system and its conversion to one less able to absorb shocks and to recover from harmful events.

Shifts in patterns of surface water temperatures in the Pacific Ocean set off changes that, combined with other factors such as snow cover in the Himalayan mountains, modify global rainfall patterns. During the El Niño phase

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of the El Niño–Southern Oscillation (ENSO), a lessening or reversal in the westerly trade winds in the equatorial Pacific causes an eastward shift in the large, warm surface ocean pool that is one of the major zones for the development of clouds and monsoon rains needed for agriculture in many areas of the world. The upwelling of cold water along the Pacific coast of South America ceases and jet streams are displaced towards the equator. These events tend to cause drought in regions with normally good rainfall and torrential rains in normally arid zones, such as the coastal desert of Peru.

The weather changes set in motion by El Niño events in the late 1800s were severe and would have even been a challenge to societies well organized to deal with disasters. However, in the countries that Davis discusses—going into great detail on India, China, and Brazil, less so on others such as the Philippines—the societies were not able or willing to cope with the extent of the disaster. The magnitude of the human destruction in the Indian droughts of the late 1800s and the callousness of the British rulers—both described in some detail—is hard to fully comprehend. (Imagine someone in the midst of a human disaster saying that the free markets need to be relied upon to deal with the situation!) And when limited relief was finally provided, people had to move some distance from their villages and perform hard labor, while receiving a food ration lower than that given to prisoners doing hard labor at Buchenwald concentration camp during the Second World War. The droughts would have been bad enough if the traditional village system for grain storage and distribution had still existed. But the British had drawn India and China into the world capitalist system and commercial relationships had replaced traditional relationships. The British also raised funds—to finance their colonial activities in India and Afghanistan—by imposing taxes that were expected to be paid even during famines. This, of course, made things worse, for when people produce less during a drought, there is no real way to earn sufficient funds to pay taxes and purchase food at exorbitant prices. The situation was made even more critical by railroads being used to bring food *from* drought stricken areas into central storage facilities, hoarding causing prices to increase (causing exorbitant prices even in areas with sufficient production) and exports to England continuing to drain food from India (as the British also imported food from Ireland during the Irish potato famine). Additional factors included the British failing to maintain traditional irrigation systems in India and compelling farmers to produce for the cash market products that could be exported—wheat, indigo, cotton, rice and, of course, the opium poppy which was forced on the Chinese people. Also making it difficult for people to survive the hard times in India were the British rules eliminating customary access to common resources ('Victorian enclosures')—forests as well as grazing lands. This made it harder to maintain livestock and to obtain firewood. With the social cohesion of Indian villages destroyed, it was not possible to organize communal activities that would benefit all, such as maintaining or improving local irrigation systems.

One way that Chinese peasants sometimes tried to deal with difficult times was to switch to cotton from growing cereal staple crops. In good years they could earn enough from selling cotton and cotton yarn and cloth (produced in the winter off-season with family labor) that they could survive off of their small plots of land. However, relying on cotton left northern Chinese peasants particularly vulnerable to droughts. Cotton is less forgiving of dry conditions and more reliant on early season rains than northern China's grain staples, sorghum and millet. Competition from foreign textiles reduced the potential of Chinese peasants to earn extra money from cottage-industry-scale spinning and weaving. Additional problems included the dwindling Chinese system of grain storage because of the financial stress of the Opium Wars, trade deficits resulting from forced opium imports, the Great Powers adoption of the gold standard in 1870s, as well as the mid-century civil wars and floods (including one that re-routed the Yellow River from entering the ocean in the Yellow Sea to the Gulf of Bohai). When disaster struck, even the use of cash (instead of stored grain) for relief could not solve the problem, because the available money couldn't keep up with the vast price inflation—there just wasn't enough locally available grain—and the difficulty of transportation to the famine areas made long-distance transport extremely expensive. Areas depopulated by deaths and migration at the times of the famines did not recover earlier population densities until the mid-20th century.

One of the outcomes of imperialism is the appropriation of resources (capital) from the periphery. Imperialist relations with India and China were especially useful to British businessmen. India was forced to be the market for products of British industry (textiles, electrical equipment, etc.) while the Indian imperialist venture was able to pay for these products by income from the sale of opium to China. This enabled Britain to import tea from China and to still have a surplus in its trade with Asia. An additional, perhaps unintended, consequence of these relationships was the development of new classes within countries of the periphery, and famines provided a special opportunity for capital accumulation and solidifying internal class and caste lines. For example, under British rule an effective market in land developed in India. This enabled money-lenders (sometimes rich peasants)—who once had a stake in the survival of a peasant borrowing in times of famine—to accumulate land holdings if peasants weren't able to pay. Rich peasants also bought animals from drought-stricken peasants, for later sale in another region not so affected by drought. The crises also worked to force a portion of the peasantry into wage labor in order to survive the drought and/or the loss of their land.

This book could have used a final editing. There is some distracting repetition and so much detail on the famines that it is almost numbing. Because the text jumps around in time and geography, it is sometimes difficult to follow. The book

would also have greatly benefited from a summary section at the end. Despite the shortcomings mentioned above, *Late Victorian Holocausts* is a very important book for those interested in agriculture and food security, partially because many of the same issues are with us today. While organizations such as the World Trade Organization might give the situation a somewhat different slant, the interests of the dominant-core wealthy countries have never stopped being a threat to feeding people in poor countries. As in the 19th century, farmers in the periphery today are also encouraged to produce crops for the export market instead of staples for their families, and as the imperialist relations at the end of the 19th century forced people into selling through limited marketing channels, agribusiness transnational corporations are currently tightening their grip on the Third World and lessening farmers' options. Additionally, as market-oriented 'solutions' were proposed for famines in the 19th century, today the 'free market' is used as an excuse to reduce assistance, such as subsidies for fertilizer purchases, to farmers in poor countries. One of the important issues of the 21st century is how to keep people productively employed on the land in rural areas—to feed themselves as well as supply some family income. Active support and assistance by governments and non-governmental organizations (NGOs) will be essential to accomplish this goal.

Fred Magdoff, Plant and Soil Science Department, University of Vermont, Burlington, Vermont, USA.
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Notes for Authors

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Examples:

1. Leopold, A. 1991. The farmer as a conservationist. In S.L. Flader and J.B. Callicott (eds). The River of the Mother of God and Other Essays by Aldo Leopold. University of Wisconsin Press, Madison, WI. p. 255–265.
2. Brink, R.H. Jr, Dubach, P., and Lynch, D.I., 1960. Measurement of carbohydrates in soil hydrolyzates with anthrone. Soil Science 89:157–166.
3. Greenland, D.J., and Szabolcs, I., (eds). 1994. Soil Resilience and Sustainable Land Use. CAB International, Wallingford, UK.
4. Arshad, M.A. and Coen, G.M., 1992. Characterization of soil quality: Physical and chemical criteria. American Journal of Alternative Agriculture 7:25–31.
5. Coale, F.J. 1996. Descriptions of the soil test interpretive categories used by the University of Maryland Soil Testing Laboratory. SFM-3. University of Maryland, College Park.

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